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STUDIES ON THE PHYSIOLOGY OF REPRODUCTION IN THE DOMESTIC FOWL.—XV. DWARF EGGS[1]

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INTRODUCTION

Eggs much smaller than normal eggs are occasionally produced by domestic fowls of all breeds. These eggs usually contain little or no yolk; but occasionally a small yolk, usually without germ disk but inclosed in a complete vitelline membrane, is present. The albumen is small in amount, and often but not always it is of a thicker consistency than the albumen of a normal egg. The egg membranes are normal. The shell varies in thickness over the same range as the shells of normal eggs. Sometimes, as in eggs otherwise normal, shell is entirely lacking—that is, the egg is simply covered with a membrane.

These small eggs are called by various names as "cock eggs," "witch eggs," "luck eggs," "wind eggs," "dwarf eggs," etc. Most of these names are associated with interesting superstitions. The term used by the people in any particular part of the world depends in part on the folklore of the region. Since no single term is generally accepted, we have decided to use a name which, although it has no legendary history, is somewhat descriptive. We have therefore called these small eggs "dwarf eggs."

Among the various types of abnormal eggs produced by the domestic fowl the dwarf egg is more common than any other type except the double-yolked egg. This type of egg has played an important rôle in the folklore of all nations. Sebillot (22),[2] Tiedeman (25), König-Warthausen (7), and Bonnet (2) give some of the popular superstitions connected with these eggs. A widespread superstition which comes down nearly to our own time is that a cock, or especially a very old cock, produces these eggs. These "cock" eggs were sometimes supposed to be made up of semen and "humors." A superstition which was quite widely accepted at an early period was that such an egg might hatch into a fabled

[1] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station, No. 98.

[2] Reference is made by numbers to "Literature cited," p. 1041.

serpent, the basilisk, whose breath or look was fatal. The basilisk was sometimes said to have head and legs like a cock. Less definite superstitions which simply regard the "cock" egg as an evil omen have also been common. In some places European peasants cast these eggs behind them over a wall or building to avoid bad luck. In other places they used them as evil charms to avenge themselves on their enemies. A very mild sort of vengeance practiced in some localities was to place one of these eggs among the eggs belonging to a neighbor. This prevented his eggs from hatching. A more violent charm was made by breaking the dwarf egg and filling part of the shell with dew collected at dawn from a white thorn tree and then exposing this to the sun. A terrible calamity was supposed to happen to the designated person as the sun drank the last drop of dew.

On the other hand, these eggs have been considered as a sign of good luck. Pearl (11) reported such a superstition which only a few years ago was accepted by a few credulous country people in some parts of the United States. According to this version of the myth a "luck egg" does not break when thrown over a building, and any wish made by the thrower while the egg is in the air is sure to come true.

The dwarf, witch, or cock egg has emerged from the age of superstition with the cause for its production inadequately explained. It is the purpose of the present paper to discuss (1) the different types of dwarf eggs in respect to shape and also in respect to contents; (2) the variability in respect to size and shape; (3) the interrelations of the variations in dimensions, shape, and size; (4) the frequency of the occurrence of dwarf eggs compared to normal eggs and of dwarf-egg producers compared to birds which do not lay dwarf eggs; (5) the seasonal distribution of dwarf eggs; (6) dwarf-egg production by birds with normal and with abnormal oviducts; (7) the relation of dwarf-egg production by normal birds to the age of the bird and to the position of the egg in the clutch and litter; (8) physiological conditions which lead to dwarf-egg production; (9) the relation of the production of dwarf eggs to other abnormal phenomena of reproduction which either occur in nature or have been experimentally produced; and (10) the contribution which the study of the physiology of dwarf-egg production makes to our knowledge of the normal physiology of egg production.

Since February, 1908, the abnormal eggs laid at the poultry plant of the Maine Agricultural Experiment Station have been brought to the laboratory for examination. In the eight years to February, 1916, 298 dwarf eggs are known to have been produced at this plant. The weight of 275 of these was taken, and in 261 of these cases the length and breadth were also measured and the length-breadth index calculated. Of the 298 eggs recorded 274 were opened, and their contents were examined. Several of the dwarf eggs were floor eggs and a few were laid by birds on which no egg record was kept. In 251 cases, however, the egg record

of the bird laying the dwarf egg is available. Furthermore, autopsies were made on several of these birds, and the condition of their sex organs was observed.

I.—CLASSIFICATION OF DIFFERENT TYPES OF DWARF EGGS, FIRST, IN RESPECT TO SHAPE, AND SECOND, IN RESPECT TO PRESENCE OR ABSENCE OF YOLK

The dwarf eggs of the fowl vary greatly in size and shape. Plate CXII shows 14 of these eggs with a normal egg laid by a 9-months-old pullet for comparison. From this illustration it may be seen that there are two distinct types of dwarf eggs in respect to their shape: The prolate-spheroidal type, similar in shape to a normal egg; and the cylindrical type, which is much longer in proportion to the breadth. The cylindrical eggs are shown in the first row of Plate CXII. These cylindrical eggs occur much less frequently than do the dwarf eggs of the prolate-spheroidal type. Of the 261 dwarf eggs on which complete data are available only 12, or 4.6 per cent, were of this form.

Not only do the dwarf eggs differ in respect to size and shape but there is a difference in internal structure. These dwarf eggs are sometimes defined as yolkless eggs, or small eggs containing a small quantity of yolk usually not in a yolk membrane. During this investigation the contents of 274 dwarf eggs were examined. It was found that some of these eggs contained no yolk but appeared to be formed around a nucleus which consisted of a few strings of coagulated albumen, apparently untwisted chalazal threads and also sometimes small lumps of hardened albumen or small blood clots. On the other hand, some contain small yolks in yolk membranes. These yolks do not usually have visible germ disks. The weight of these yolks varies from 1 gm. to nearly 8 gm. More than half of all the eggs opened, however, contained some yolk which was not inclosed in a yolk membrane. Dwarf eggs may then be classified according to the nonoccurrence of yolk and the condition of the yolk when present as, first, yolkless, second, with some yolk not in a membrane, and third, with one small yolk. In Table I the dwarf eggs are classified both according to form and yolk content.

TABLE I.—*Classification of dwarf eggs both as to shape and as to yolk content*

Shape.	Number yolkless.	Percentage yolkless.	Number with some yolk not in a membrane.	Percentage with some yolk not in a membrane.	Number with one small yolk.	Percentage with one small yolk.	Total.
Shape not known [a]	5	38.46	8	61.54	0	0	13
Prolate-spheroidal shape	83	33.33	139	55.82	27	10.84	249
Cylindrical shape	8	66.67	4	33.33	0	0	12
Total	96	35.03	151	55.11	27	9.85	274

[a] Dimensions not recorded.

From the last line of Table I it is seen that 96, or 35.03 per cent, of the eggs opened were yolkless. The other 178, or 64.96 per cent, contained yolk. Of these, 151, or 55.11 per cent, of all the dwarf eggs opened contained yolk not inclosed in a yolk membrane. A small yolk was present in 27, or 9.85 per cent, of the dwarf eggs. From these figures it is seen that nearly two-thirds of the dwarf eggs contain yolk.

II.—THE ALBUMEN AND SHELL OF DWARF EGGS

We have seen that dwarf eggs differ in respect to the nucleus around which the albumen is formed. Bonnet (3) states that the nature of the albumen is also generally altered. The dwarf eggs observed differed greatly in respect to the density of the albumen. In many it was very condensed, being a thick clear mass which nearly maintained its shape when removed from the shell and egg membranes. It appeared very much like the albumen in a normal egg while it is in the albumen-secreting region, or the isthmus of the oviduct (15). In many other cases it appeared exactly like the albumen of a normal laid egg—that is, there was a somewhat firm inner mass surrounded by a thin fluid albumen. All gradations between these also occurred. In a very few cases the albumen was more fluid than in the average normal egg. There was, however, an undoubted general tendency for the albumen to be more than normally firm. The density of the albumen was not determined accurately as a routine procedure in the dwarf eggs. Its apparent density as compared to normal eggs was frequently, but unfortunately not uniformly, recorded. In connection with another investigation in progress at this laboratory the specific gravity and refractive index of the albumen of many normal and a few dwarf eggs was determined. These probably were not a random sample of dwarf eggs. The minimum specific gravity of the sample of 7 dwarf eggs was 1.02824, while the mean specific gravity for the sample of 180 normal eggs was 1.0288. The dwarf eggs ranged widely, with the upper end of the range decidedly above that for normal eggs. The maximum for dwarf eggs was 1.2107, against a maximum of 1.0415 for the normal eggs. The mean for the dwarf eggs was 1.0627, which is higher than the maximum for normal eggs. The range, however, overlaps, 4 of the 7 dwarf eggs falling within the upper end of the range for normal eggs. In a sample of 10 dwarf eggs the refractive index lay within the range for the sample of 180 normal eggs. The mean was slightly higher for the dwarf than for the normal eggs; but this difference certainly was not significant.

The egg membranes of dwarf eggs, so far as superficial appearances indicate, are comparable to those of normal eggs. The shell is sometimes entirely or almost entirely absent, as in the case of membrane-covered or soft-shelled eggs, which are normal in all other particulars. The thickness of shell varies from very thin to very thick, as in normal eggs.

In the present investigation no further distinction is made between dwarf eggs in respect to variation in albumen or shell.

III.—SIZE AND SHAPE RELATIONS OF THE SEVERAL CLASSES OF DWARF EGGS COMPARED TO EACH OTHER AND TO NORMAL EGGS AND THE RELATIVE VARIABILITY OF NORMAL AND OF THE DIFFERENT CLASSES OF DWARF EGGS

There is a considerable amount of variation within each class of dwarf eggs in respect to every measurable character. Table II gives for each class the frequency distribution of variation for each dimension, the shape index, and the weight.

TABLE II.—*Frequency distributions of the variation in size and shape of the several classes of dwarf eggs*

LENGTH

Class.	Frequency of prolate-spheroidal shape.			Frequency of cylindrical shape.	
	Yolkless.	Some free yolks.	A small yolk	Yolkless.	Some free yolk
Mm.					
20.0–22.9	1	1			
23.0–25.9	2	1			1
26.0–28.9	5	11		1	0
29.0–31.9	14	32		0	0
32.0–34.9	16	25	1	0	2
35.0–37.9	23	16	6	3	1
38.0–40.9	11	23	4	1	
41.0–43.9	6	16	7	0	
44.0–46.9	5	7	7	1	
47.0–49.9		5	1	0	
50.0–52.9		1		1	
53.0–55.9				0	
56.0–58.9				1	
Total	83	[a] 138	[a] 26	8	4

BREADTH

Class.	Yolkless.	Some free yolks.	A small yolk	Yolkless.	Some free yolk
Mm.					
6.0– 7.9					1
8.0– 9.9					0
10.0–11.9					0
12.0–13.9					0
14.0–15.9					1
16.0–17.9					1
18.0–19.9	1	1		1	0
20.0–21.9	3	3		1	0
22.0–23.9	7	5		3	1
24.0–25.9	7	18		0	
26.0–27.9	15	35	1	3	
28.0–29.9	25	25	6		
30.0–31.9	20	20	5		
32.0–33.9	6	18	5		
34.0–35.9	1	9	7		
36.0–37.9		4	1		
38.0–39.9			1		
Total	83	[a] 138	[a] 26	8	4

[a] Two dwarf eggs of prolate-spheroidal shape, one with some free yolk and one with a small yolk, were laid after the frequency constants and correlation coefficients had been calculated. These eggs are included in Table I, but not in Table II, III, IV, or V.

TABLE II.—*Frequency distribution of the variation in size and shape of the several classes of dwarf eggs*—Continued.

EGG WEIGHT

Class.	Frequency of prolate-spheroidal shape.			Frequency of cylindrical shape.	
	Yolkless.	Some free yolks.	A small yolk.	Yolkless.	Some free yolk.
Gm.					
3.0– 5.9	2	1	....	1	1
6.0– 8.9	6	7	....	0	0
9.0–11.9	10	17	....	2	1
12.0–14.9	9	34	1	1	2
15.0–17.9	21	18	5	0	....
18.0–20.9	15	12	2	3	....
21.0–23.9	9	15	3	0	....
24.0–26.9	5	16	3	1	....
27.0–29.9	6	9	6	....	....
30.0–32.9	....	3	4	....	....
33.0–35.9	....	5	2	....	....
36.0–38.9	....	1	....	....	....
Total	83	[a] 138	[a] 26	8	4

INDEX

Class.	Yolkless.	Some free yolks.	A small yolk.	Yolkless.	Some free yolk.
Per cent.					
34.0–36.9	....	....	....	....	1
37.0–39.9	....	....	....	....	0
40.0–42.9	....	....	....	....	0
43.0–45.9	....	....	....	....	0
46.0–48.9	....	....	....	1	1
49.0–51.9	....	....	....	0	1
52.0–54.9	....	....	....	1	0
55.0–57.9	....	....	....	3	0
58.0–60.9	....	....	....	1	1
61.0–63.9	....	....	....	1	....
64.0–66.9	1	3	1	1	....
67.0–69.9	2	5	1	....	....
70.0–72.9	3	6	0	....	....
73.0–75.9	16	14	2	....	....
76.0–78.9	11	15	9	....	....
79.0–81.9	12	21	6	....	....
82.0–84.9	17	31	6	....	....
85.0–87.9	12	25	1	....	....
88.0–90.9	6	10	....	....	....
91.0–93.9	2	7	....	....	....
94.0–96.9	1	1	....	....	....
Total	83	[a] 138	[a] 26	8	4

[a] Two dwarf eggs of prolate-spheroidal shape, one with some free yolk and one with a small yolk, were laid after the frequency constants and correlation coefficients had been calculated. These eggs are included in Table I, but not in Table II, III, IV, or V.

The size and variation of the different egg parts in dwarf eggs is an interesting but difficult question. It was found possible to separate accurately the parts in a dwarf egg with a small yolk inclosed in yolk

membrane. The method employed was the one in routine use at this laboratory (3). The egg was first weighed; then the egg was broken and the parts separated. The yolk and shell were wiped as dry as possible with filter paper and weighed. The weight of albumen was determined by difference. The weights of the parts were determined for 16 of the small-yolked dwarf eggs. This number is so small that the variation and correlation were studied directly from the ungrouped data. These data are given in Table III.

The frequency constants calculated from the distributions in Table II and from the data in Table III are given in Table IV.

TABLE III.—*Weight of egg and of each of the egg parts for the 16 dwarf eggs on which these data were taken*

Egg No.	Weight of egg.	Weight of yolk.	Weight of albumen.	Weight of shell.
	Gm.	*Gm.*	*Gm.*	*Gm.*
1	20.00	0.85	15.50	3.65
2	17.00	1.00	12.00	4.00
3	18.40	1.85	12.75	3.80
4	24.50	2.19	19.09	3.22
5	20.00	2.50	12.50	5.00
6	22.50	3.55	16.70	2.25
7	24.85	4.37	17.10	3.38
8	29.00	4.50	20.00	4.50
9	24.75	4.53	16.17	4.05
10	30.00	5.00	21.25	3.75
11	20.00	5.50	20.00	3.50
12	31.00	5.50	21.00	4.50
13	32.50	6.50	18.50	7.50
14	30.33	6.50	19.83	4.00
15	32.00	7.00	20.25	4.75
16	34.00	7.00	22.00	5.00
Mean	26.24 ± 0.82	4.27 ± 0.34	17.79 ± 0.53	4.18 ± 0.19

The variation constants were not calculated for cylindrical eggs either with or without yolk, since the number is so small that these constants would be meaningless. The arithmetical mean in these cases was calculated directly from the data. For the sake of comparison the Table IV also gives the constants determined by Curtis (4) from the 3,180 normal eggs laid by a flock of 22 Barred Plymouth Rock birds during their pullet year, and the constants determined by Pearl and Surface (20) for the 450 eggs laid by an 850-bird flock of Barred Plymouth Rock pullets on February 12, 1908. The constants from the two series agree closely and may be considered a fair measure of the variation in the physical characters of the normal Barred Plymouth Rock egg. Since the second set of constants is based on a group of eggs, no two of which were laid by the same bird, they are theoretically the better measure of a random sample of Barred Plymouth Rock eggs.

TABLE IV.—*Constants of variation in size and shape in the several types of dwarf eggs and in normal eggs*

Character.	Dwarf eggs.					All normal first-year eggs from 22-bird flock.	All eggs laid by 850 birds on Feb. 12, 1908.
	Prolate-spheroidal shape.			Cylindrical shape.			
	Yolkless.	Some free yolk.	A small yolk.	Yolkless.	Some free yolk.		
Number of eggs	83	138	26	8	4	3,180	450
Length:							
Mean	35.27±0.37	35.84±0.34	41.35±0.50	41.68	31.3	55.70±0.03	56.32±0.08
Standard deviation	5.03± .26	5.88± .24	3.81± .36	...	...	2.41± .02	2.39± .05
Coefficient of variation	14.26± .76	16.40± .68	9.22± .87	...	...	4.33± .04	4.24± .09
Breadth:							
Mean	28.23± .24	28.94± .21	32.38± .38	23.59	15.73	41.14± .02	41.92± .04
Standard deviation	3.20± .17	3.61± .15	2.87± .27	...	...	1.41± .01	1.38± .03
Coefficient of variation	11.34± .60	12.48± .51	8.85± .83	...	...	3.44± .03	3.29± .07
Index:							
Mean	80.75± .44	81.54± .36	78.88± .59	57.57	48.67	73.95± .04	74.52± .12
Standard deviation	5.96± .37	6.31± .26	4.41± .42	...	...	3.30± .03	3.79± .09
Weight:							
Mean	17.11± .43	18.35± .41	24.81± .81	15.24	10.63	52.92± .06	55.26± .15
Standard deviation	5.86± .31	7.14± .29	6.13± .57	...	...	5.01± .04	4.62± .10
Coefficient of variation	34.24±1.99	38.90±1.80	24.70±2.45	...	...	9.46± .08	8.36± .19
Weight:							
Mean	...	...	[a]26.24± .82	...	...	...	...
Standard deviation	...	...	[a]5.29± .63	...	...	...	...
Coefficient of variation	...	...	[a]20.15±2.50	...	...	...	...
Yolk weight:							
Mean	...	...	[a]4.27± .34	...	...	15.77± .02	...
Standard deviation	...	...	[a]2.01± .24	...	...	1.78± .02	...
Coefficient of variation	...	...	[a]47.12±6.75	...	...	11.31± .11	...
Albumen weight:							
Mean	...	...	[a]17.79± .53	...	...	31.55± .05	...
Standard deviation	...	...	[a]3.15± .37	...	...	3.87± .04	...
Coefficient of variation	...	...	[a]17.69±2.18	...	...	12.27± .11	...
Shell weight:							
Mean	...	...	[a]4.18± .19	...	...	5.12± .01	...
Standard deviation	...	...	[a]1.10± .13	...	...	.71± .01	...
Coefficient of variation	...	...	[a]26.31±3.35	...	...	13.86± .13	...

[a] Calculated directly from the data (Table III) for the 16 eggs on which the weights of the parts were known.

The flocks which produced the dwarf eggs were largely composed of Barred Plymouth Rock birds from 5 to 17 months of age—that is, the birds were for the most part of the same age and strain as those producing the eggs from which the normal variation constants were calculated. Most of the dwarf eggs were produced by birds of this age and strain. A few were produced by birds of other breeds and a few by older birds. Barred Plymouth Rock birds in their first year produced dwarf eggs which extend over the whole range of size and shape. The slight heterogeneity of the material can not have so materially affected

the variation constants that it is unfair to compare them with the constants for normal Barred Plymouth Rock eggs.

By means of the data given in Tables II, III, and IV it is possible to compare the size, shape, and degree of variability of the several groups of dwarf eggs both among themselves and with normal eggs.

A.—SIZE RELATION OF DWARF AND NORMAL EGGS

The means given in Table IV show mathematically that all classes of dwarf eggs are of lighter weight and both shorter and narrower than normal eggs. This fact is, of course, obvious from the most casual inspection of dwarf and normal eggs. In comparing the different classes of dwarf eggs with each other it is necessary to keep in mind that the number of cylindrical eggs is so small that the means determined may not represent the true means for this class of eggs. Of the eggs studied, however, the mean prolate-spheroidal, or egg-shaped, egg was decidedly heavier than the mean cylindrical egg. It was also decidedly broader. It can be seen from the means given in the table that the mean weight and the mean breadth for both groups of cylindrical eggs are smaller than the mean for the same character for any group of the prolate-spheroidal eggs. The mean lengths for all cylindrical and all prolate-spheroidal eggs may be compared by calculating from the means in Table IV the weighted mean for each of these shape groups. The mean length for the cylindrical eggs is 38.22 and for the prolate-spheroidal eggs it is 36.23—that is, the cylindrical eggs studied were much lighter in weight, decidedly narrower, but slightly longer than the eggs of the prolate-spheroidal type.

The number of each class of cylindrical eggs is so small that the comparisons of the means for the two classes is of very doubtful meaning. A comparison of the means for the several groups of prolate-spheroidal eggs seems to show that those with small yolks average longer, broader, and heavier than those of the other groups, while the means for the dwarf eggs with some yolk not in membrane (free yolk) are slightly higher than for yolkless dwarf eggs. While the number of dwarf eggs in each group of prolate-spheroidal eggs is larger than in the case of cylindrical dwarf eggs, the actual number is not very large. In order to determine whether or not the above noted differences are greater than those which might arise from errors in sampling, each difference is compared with its probable error. The first section of Table V gives for each physical character measured the deviation in mean with the probable error, and the ratio of the error to the deviation between normal eggs[1]

[1] Since the constants derived from the [illegible] eggs laid on the same day are measures of an absolutely random sample of Barred Plymouth Rock eggs, these constants are used in calculating the difference between dwarf and normal eggs in the case of length, breadth, index, and weight. Data on the weight of the egg parts were not taken on the [illegible] egg series. Therefore the only available constants for these characters are those determined from all of the first-year eggs of the small flock.

and small-yolked dwarf eggs, between small-yolked and free-yolked dwarf eggs, and between free-yolked and yolkless dwarf eggs.

TABLE V.—*Deviation between normal eggs and egg-shaped dwarf eggs and between the different classes of egg-shaped dwarf eggs for the mean and coefficient of variation of each measured character*

Character.	Classes compared.	Difference in mean with probable error.	Difference ÷ Probable error of a difference.
Length	Normal [a]—small-yolked dwarf	14. 97±0. 51	29. 4
Do	Small-yolked—free-yolked dwarf	5. 51± . 60	9. 2
Do	Free-yolked—yolkless dwarf	. 57± . 50	1. 1
Breadth	Normal [a]—small-yolked dwarf	9. 54± . 38	24. 5
Do	Small-yolked—free-yolked dwarf	3. 14± . 43	8. 0
Do	Free-yolked—yolkless dwarf	. 71± . 32	2. 2
Index	Normal [a]—small-yolked dwarf	−4. 36± . 60	7. 3
Do	Small-yolked—free-yolked dwarf	−2. 66± . 69	3. 9
Do	Free-yolked—yolkless dwarf	. 79± . 57	1. 4
Weight	Normal [a]—small-yolked dwarf	30. 45± . 82	37. 1
Do	Small-yolked—free-yolked dwarf	6. 46± . 91	7. 1
Do	Free-yolked—yolkless dwarf	1. 24± . 59	2. 1
Yolk weight	Normal [b]—small-yolked dwarf [c]	11. 50± . 34	33. 8
Albumen weight	do	13. 76± . 53	26. 0
Shell weight	do	. 94± . 19	4. 9

Character.	Classes compared.	Deviation in coefficient of variation with probable error of difference.	Deviation in coefficient of variation ÷ Probable error of difference.
Length	Free-yolked—yolkless dwarf	2. 14±1. 02	2. 1
Do	Yolkless—small-yolked dwarf	5. 04±1. 15	4. 4
Do	Small-yolked dwarf—normal [a]	4. 98± . 87	5. 7
Breadth	Free-yolked—yolkless dwarf	1. 14± . 79	1. 4
Do	Yolkless—small-yolked dwarf	2. 49±1. 02	2. 4
Do	Small-yolked dwarf—normal [a]	5. 56± . 83	6. 7
Weight	Free-yolked—yolkless dwarf	4. 66±2. 68	1. 7
Do	Yolkless—small-yolked dwarf	9. 54±3. 16	3. 0
Do	Small-yolked dwarf—normal [a]	16. 34±2. 46	6. 6
Yolk weight	Small-yolked dwarf [c]—normal [b]	35. 81±6. 75	5. 3
Albumen weight	do	5. 42±2. 18	2. 5
Shell weight	do	12. 45±3. 35	3. 7

[a] Calculated from the 430 eggs laid by the flock on a single day.
[b] Calculated from all of the 3,180 eggs laid by a flock of 22 pullets during their first laying year.
[c] Calculated direct from the data for the 16 small-yolked dwarf eggs for which the weights of the parts were known.

It is customary to consider a difference smaller than twice the probable error as probably not significant, a difference between two and three times its probable error as of a doubtful significance, and a difference three or more times the error as certainly or almost certainly significant.

Pearl and Miner (17) have published a table showing, for each value of the ratio of the probable error to the deviation, the probable occurrence in a hundred trials of a deviation as great or greater than the observed, provided chance alone is operating, and also the odds against its occurrence. From this table we see that the odds against a deviation due to chance alone, which is 3.0 times its probable error, is 22.26 to 1. We also see that above 3.0 the increase in odds is very rapid. At 4.0 it is 142.26 to 1; at 5.0 it is 1,350.35 to 1; at 8.0 it is 1,470,588,234 to 1. In the present discussion a deviation less than twice its probable error is considered insignificant. The significance of a deviation between two and three times the probable error is considered doubtful. A deviation between three and four times its probable error is considered probably significant. A deviation four or more times its probable error is considered almost certainly significant, with the understanding that when the odds against the occurrence of a given deviation being due to chance alone are as great or greater than 142.26 to 1, the deviation is almost certainly due to some other cause than error of sampling.

From Table V we see that small-yolked dwarf eggs are significantly smaller than normal eggs and larger than the other classes of dwarf eggs. These significant differences are seen in length, breadth, and weight [1]—that is, the small-yolked egg is nearer the size of a normal egg than are dwarf eggs with little or no yolk. The average length, breadth, and weight are all slightly higher for dwarf eggs which contain some free yolk than for yolkless dwarf eggs. These slight differences may be due to errors in sampling, since in no case is the deviation three times its probable error—that is, although the mean size of the observed dwarf eggs with some free yolk is slightly greater than the mean size of the observed yolkless dwarf eggs, this difference is not certainly significant.

These results are in line with the results from other investigations on the size of eggs. First, Pearl (12) showed that the relation of the weight of the entire egg to the number of yolks contained (zero, one, two, or three) is very accurately described by a parabola. He concluded that, while the size of eggs is not directly proportional to the number of yolks they contain, a definite relation probably exists between the amount of albumen secreted and the amount of yolk present in the duct in a given case. Second, Curtis (5) showed that within the eggs of an individual bird the actual weight of both albumen and shell is higher in triple-yolked than in double-yolked and higher in double-yolked than in single-yolked eggs. The increase in these accessory parts is not, however, proportional to the increase in yolk weight, since the yolk which formed only 24.37 per cent of the normal eggs formed 33.91 per cent of the double-yolked and 35.52 per cent of the triple-yolked eggs. Third, Curtis (4) showed that in the normal eggs of each individual bird there is a significant

[1] The weight of each egg part is also significantly smaller in small-yolked dwarf than in normal eggs.

correlation between the weight of the yolk and the weight of the albumen—that is, the amount of albumen secreted is in part at least dependent on the amount of immediate stimulation due to the quantity of yolk in the duct.

The results recorded for the different classes of dwarf eggs carry these results further. The eggs which contain small-formed yolks are smaller than normal eggs and larger than eggs which contain either little or no yolk. That eggs with a small amount of free yolk are not certainly significantly larger than eggs without yolk is explained by the fact that the two groups were separated strictly on a basis of the presence or absence of yolk. Dwarf eggs which do not contain formed yolks contain as nuclei lumps or drops of free yolk, lumps of hardened secretion, blood clots, or fibers of coagulated albumen. The size of these nuclei vary considerably. A single drop or a very small lump of yolk threw the egg into the class of free-yolked dwarf eggs. Several yolkless dwarf eggs contained nuclei larger than some of the lumps or drops of yolk found in the free-yolked dwarf eggs. In a broad way at least the size of the egg varies with the size of the nucleus—that is, a large dwarf egg contains a considerable amount of yolk or some other large nucleus. A very small one contains a small nucleus. Since the irregular particles can not be accurately measured, the degree of this relationship [1] can not be ascertained.

A comparison of the mean egg size of the several groups of dwarf eggs classified according to yolk content confirms the evidence obtained from a study of normal and multiple-yolked eggs that the amount of yolk (or other nucleus) present in the oviduct is an important factor in determining the amount of albumen secreted in a given case.

B.—RELATIVE SHAPE OF DWARF AND NORMAL EGGS

Tables IV and V also give data for a study of the comparative shape of the several classes of dwarf and of normal eggs. It has already been noted that there are two distinct shape groups of dwarf eggs: Cylindrical and prolate-spheroidal eggs. A comparison of the mean indices shows that cylindrical dwarf eggs are longer in proportion to their breadth than are normal eggs, while prolate-spheroidal eggs are proportionately shorter than normal eggs. It is also seen that dwarf eggs with small yolks are nearer the shape of normal eggs than are dwarf eggs without formed yolks.

The cause for the distinctly different form in cylindrical and prolate-spheroidal dwarf eggs can not be certainly decided from the material at hand. In several cases of cylindrical dwarf eggs the form of the nucleus was not noted. However, in a few pronounced cases it was noted that

[1] On page 1000 it is shown that in dwarf eggs with formed yolks the yolk weight is highly correlated both with the egg weight and the albumen weight.

the nucleus of coagulated fibers of albumen was drawn out in a line parallel to the long axis of the egg. Further, at one of our routine autopsies there was found in an oviduct a string of albumen 5 or 6 cm. long and not more than 1 cm. in diameter. This was wrapped around a long thread of coagulated albumen fibers which lay parallel to the length of the duct. It seems probable that the form of the stimulating nucleus is one of the factors in determining the shape of the egg. When the stimulus is small in amount and drawn out, the degree of stimulation must be small but the area covered large.

In the prolate-spheroidal eggs the nucleus is usually of globular form—that is, its shape is comparable to the shape of a normal yolk. All the eggs with small-formed yolks were of the prolate-spheroidal type. It has been noted that indices for dwarf eggs with small yolks are higher than those for normal eggs and lower than those for other prolate-spheroidal eggs. The order for the value of index is thus the reverse of the order for the size characters. Later it will be shown that within each group of dwarf eggs the index is negatively correlated with weight. In earlier investigations (3, 5) it has been shown, first, that the indices for multiple-yolked eggs lie below the range of variation for the indices of normal eggs, and, second, that within the normal eggs of an individual the index is negatively correlated with weight. The results from the study of dwarf eggs, therefore, extend the former evidence that the smaller the egg the broader it is in proportion to its length. Two factors may be working together to produce this negative correlation between index and weight. First, the greater the long diameter of the nucleus—be it yolk drop, normal yolk, or two or three yolks in tandem—the longer will be the area of oviduct stimulated at the same time; and, second, when a plastic body is forced (by peristalsis) through an elastic tube the tube will offer less mechanical resistance to the passage of a small than a large body. This mechanical factor is probably of great importance in determining the shape of the egg.

C.—RELATIVE VARIABILITY OF DWARF AND NORMAL EGGS

Tables IV and V give also the data for comparing the variability of the different classes of prolate-spheroidal dwarf eggs with each other and with normal eggs. Table IV gives for normal eggs and for each class of egg-shaped dwarf eggs the standard deviation for length, breadth, index, and weight, and the coefficient of variation for each of these characters except index.[1] In the case of normal eggs and dwarf eggs with formed yolks it also gives the variation constants for each egg part (yolk, albumen, and shell). A comparison either of standard deviations or of coefficients of variation shows that normal eggs are less variable in each character measured than are the eggs of any class of prolate-spheroidal dwarf eggs. The

[1] Coefficients of variation of percentage characters have no physical significance.

most variable class of dwarf eggs is apparently those which have some free yolk, while the yolkless dwarf eggs are more variable than the small-yolked dwarf eggs—that is, the small-yolked dwarf egg approaches the normal in degree of variability as well as in size and shape. In comparing classes where the absolute difference in size is as great as it is between normal and dwarf eggs the coefficients of variation are more accurate measures of relative variability than are the standard deviations. In order to determine whether or not the apparent difference in degree of variability shown by the several classes is significant, it is necessary to compare these differences with their probable errors. The second section of Table V shows these differences in the size characters with their probable errors and the ratio of each difference to its probable error. From this table we see, first, that normal eggs are significantly less variable than the least variable class of dwarf eggs (small-yolked dwarf eggs) in length, breadth, egg weight, yolk weight, and probably shell weight. The significance of the smaller variation in albumen weight is doubtful. Second, small-yolked dwarf eggs are almost certainly less variable than other dwarf eggs in length and probably also in weight. The significance of the smaller variation in breadth is doubtful. Third, the somewhat greater variation in every size character in the dwarf eggs with free yolk than in the yolkless eggs is not certainly significant—that is, it may be due to errors in sampling.

As previously stated, the coefficient of variation of index, which is a percentage character, has no physical meaning. Since the index equals the percentage that the breadth is of the length, all the indices are measured in the same units and have the same possibilities of variation in range. There is, then, less objection to comparing the standard deviations of such a character; in fact, such a comparison is the only available measure of the relative variability in shape of the several groups. However, too much reliance should not be placed on the figures. The differences in the standard deviations of the indices for the different groups are as follows:

Free-yolked—yolkless dwarf	$=0.35\pm0.40$
Yolkless—small yolked dwarf	$=1.55\pm\ .52$
Small-yolked dwarf—normal	$=\ .62\pm\ .43$

The only deviation which can be considered of even probable significance is the difference between yolkless and small-yolked dwarf eggs—that is, normal eggs and small-yolked dwarf eggs are probably less variable in shape than dwarf eggs without a formed yolk.

The relative variability of the size characters within each group is also of some interest. From Table IV it may be seen that the order of variability of the size characters of the egg is the same in normal eggs and in each class of the dwarf eggs. The size characters arranged in the order of their variability from most to least variable are (1) egg weight,

(2) length, and (3) breadth. In order to determine whether or not these apparent differences may be considered significant, the differences with their probable errors and the ratio of each difference to its probable error are given in Table VI.

TABLE VI.—*Difference between the coefficients of variation in the size characters, together with the probable error of difference and the ratio of each difference to its probable error, for normal eggs and for each class of egg-shaped dwarf eggs*

Class.	Characters compared.	Difference in coefficient of variation, with probable error.	Difference ÷ probable error of difference
Normal eggs [a]	Egg weight—length	4.12±0.21	19.6
Do.	Length—breadth	.95± .11	8.6
Small-yolked dwarf eggs.	Egg weight—length	15.48±2.60	6.0
Do.	Length—breadth	.37±1.20	.3
Free-yolked dwarf eggs	Egg weight—length	22.50±1.92	11.7
Do.	Length—breadth	3.92± .85	4.6
Yolkless dwarf eggs	Egg weight—length	19.98±2.13	9.4
Do.	Length—breadth	2.92± .97	3.0

[a] From 450 eggs laid by a flock of Barred Plymouth Rock pullets in a single day.

From Table VI it appears that the order of variability of the characters is probably significant—that is, in both normal and dwarf eggs the size characters may be arranged in the order of their variability as egg weight, length, and breadth. The only case where the difference is less than three times its probable error is between length and breath in "cock eggs" with small yolks. In this case the deviation might have been due to errors of sampling.

In normal eggs it has been shown by Curtis (4) that the weight of the whole egg is less variable than the weight of any part (yolk, albumen, or shell). Of the three parts the shell is the most and the yolk the least variable. The coefficients calculated for 16 dwarf eggs with small yolks do not show the same relative variability of the parts. In these eggs the weight of albumen was less variable than the weight of the whole egg, and the yolk weight instead of being the most constant of the three parts was the most variable. The number of eggs, however, is so small that the probable error of sampling is large. Table VII shows that when the coefficients of variation of the egg parts are arranged in the order of their value, the differences between the two of nearest value is in no case equal to three times the probable error of difference. It is, however, probable that yolk weight is more variable compared to the weight of the other parts and to the whole egg in small-yolked dwarf than in normal eggs.

TABLE VII.—*Relative variability of the whole and the several parts of normal eggs and of dwarf eggs with small yolks*

NORMAL EGGS [a]

Characters compared.	Difference in coefficient of variation with probable error.	Difference ÷ probable error of difference.
Shell weight—albumen weight	1.59±0.17	9.4
Albumen weight—yolk weight	.96± .16	6.0
Yolk weight—egg weight	1.85± .14	13.2

SMALL-YOLKED DWARF EGGS [b]

Characters compared.	Difference in coefficient of variation with probable error.	Difference ÷ probable error of difference.
Yolk weight—shell weight	20.81±7.54	2.8
Shell weight—albumen weight	8.62±4.00	2.1
Egg weight—albumen weight	2.46±3.32	.7

[a] From 3,180 eggs laid by flock of 22 Barred Plymouth Rock pullets.
[b] Coefficients calculated direct from data for the 16 dwarf eggs of known yolk weight.

IV.—INTERRELATION OF THE DIMENSIONS, SHAPE, AND WEIGHT OF EACH CLASS OF DWARF EGGS COMPARED TO THE SAME RELATIONS IN NORMAL EGGS

We have seen that the dwarf eggs of each group vary greatly in each dimension and in weight and shape. We shall now consider the correlation in the variation of the several characters in prolate-spheroidal[1] dwarf eggs of each class. It will be determined whether a long dwarf egg is broader or narrower than a short one of the same class; whether a large dwarf egg of any class is longer or broader or both longer and broader than a small egg of the same class; whether a large dwarf egg is longer or shorter in proportion to its breadth than a small dwarf of the same group; and whether or not these relations are the same in the several groups of dwarf eggs and in normal eggs. In the case of dwarf eggs with formed yolk the relation between yolk weight and albumen weight is also studied.

The correlations studied then are length with breadth, breadth with weight, length with weight, index with weight, yolk weight with egg weight, and yolk weight with albumen weight. On account of the small number of dwarf eggs of known yolk weight, the correlations involving yolk weight were calculated directly from the data given in Table III. In the case of the other pairs of characters the usual correlation tables were made for each class of dwarf eggs. These are shown as Tables VIII to XIX, inclusive.

[1] Cylindrical eggs appear to show the same relations among themselves as the prolate-spheroidal eggs, but the number is too small to determine the significance of the relationship.

TABLE VIII.—*Correlation between egg breadth and egg length in dwarf eggs with some yolk not in a yolk membrane*

Egg length (in millimeters).	Egg breadth (in millimeters).										
	18.00–19.99	20.00–21.99	22.00–23.99	24.00–25.99	26.00–27.99	28.00–29.99	30.00–31.99	32.00–33.99	34.00–35.99	36.00–37.99	Total.
20.00–22.99	1										1
23.00–25.99		1									1
26.00–28.99		1	3	5	2						11
29.00–31.99		1	1	7	22	1					32
32.00–34.99			1	5	9	10					25
35.00–37.99				1	2	5	7	1			16
38.00–40.99						8	7	7	1		23
41.00–43.99						1	4	5	5	1	16
44.00–46.99							1	1	3	2	7
47.00–49.99							1	3		1	5
50.00–52.99								1			1
Total	1	3	5	18	35	25	20	18	9	4	138

TABLE IX.—*Correlation between egg breadth and egg length in dwarf eggs without yolk*

Egg length (in millimeters).	Egg breadth (in millimeters).									
	18.00–19.99	20.00–21.99	22.00–23.99	24.00–25.99	26.00–27.99	28.00–29.99	30.00–31.99	32.00–33.99	34.00–35.99	Total.
20.00–22.99	1									1
23.00–25.99		1	1							2
26.00–28.99		1	3	1						5
29.00–31.99		1	3	3	6	1				14
32.00–34.99				3	2	10	1			16
35.00–37.99					6	8	9			23
38.00–40.99					1	3	4	2	1	11
41.00–43.99						1	4	1		6
44.00–46.99							2	3		5
Total	1	3	7	7	15	23	20	6	1	83

TABLE X.—*Correlation between egg breadth and egg length in dwarf eggs with small yolks*

Egg length (in millimeters).	Egg breadth (in millimeters).							
	26.00–27.99	28.00–29.99	30.00–31.99	32.00–33.99	34.00–35.99	36.00–37.99	38.00–39.99	Total.
32.00–34.99		1						1
35.00–37.99		4	2					6
38.00–40.99			2	1	1			4
41.00–43.99	1	1	1	3		1		7
44.00–46.99				1	6			7
47.00–49.99							1	1
Total	1	6	5	5	7	1	1	26

TABLE XI.—*Correlation between egg weight and egg length in dwarf eggs with some yolk not in a yolk membrane*

Egg length (in millimeters).	Egg weight (in grams).												
	3.00–5.99	6.00–8.99	9.00–11.99	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	30.00–32.99	33.00–35.99	36.00–38.99	Total.
20.00–22.99	1	...	...	...	...	...	...	...	...	...	...	...	1
23.00–25.99	...	1	...	...	...	...	...	...	...	...	...	...	1
26.00–28.99	...	5	5	1	...	...	...	...	...	...	...	...	11
29.00–31.99	...	1	10	20	1	...	...	...	...	...	...	...	32
32.00–34.99	...	...	2	10	12	1	...	...	...	...	...	...	25
35.00–37.99	...	...	...	3	4	5	4	...	...	...	...	...	16
38.00–40.99	...	...	...	...	1	5	8	8	1	...	...	...	23
41.00–43.99	...	...	...	...	...	1	2	7	4	1	1	...	16
44.00–46.99	...	...	...	...	...	...	...	1	2	...	4	...	7
47.00–49.99	...	...	...	...	...	...	1	...	2	1	...	1	5
50.00–52.99	...	...	...	...	...	...	...	...	...	1	...	...	1
Total	1	7	17	34	18	12	15	16	9	3	5	1	138

TABLE XII.—*Correlation between egg weight and egg length in dwarf eggs without yolk*

Egg length (in millimeters).	Egg weight (in grams).									
	3.00–5.99	6.00–8.99	9.00–11.99	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	Total.
20.00–22.99	1	...	...	...	...	...	...	...	...	1
23.00–25.99	1	1	...	...	...	...	...	...	...	2
26.00–28.99	...	3	2	...	...	...	...	...	...	5
29.00–31.99	...	1	7	4	1	1	...	...	...	14
32.00–34.99	...	1	1	3	11	...	...	...	...	16
35.00–37.99	...	...	...	2	8	10	3	...	...	23
38.00–40.99	...	...	...	...	1	4	3	2	1	11
41.00–43.99	...	...	...	...	...	...	3	2	1	6
44.00–46.99	...	...	...	...	...	...	...	1	4	5
Total	2	6	10	9	21	15	9	5	6	83

TABLE XIII.—*Correlation between egg weight and egg length in dwarf eggs with small yolks*

Egg length (in millimeters).	Egg weight (in grams).								
	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	30.00–32.99	33.00–35.99	Total.
32.00–34.99	......	1	......	......	......	......	......	......	1
35.00–37.99	1	3	2	......	......	......	......	......	6
38.00–40.99	......	......	......	2	1	1	......	......	4
41.00–43.99	......	1	......	1	2	2	......	1	7
44.00–46.99	......	......	......	......	......	2	4	1	7
47.00–49.99	......	......	......	......	......	1	......	......	1
Total	1	5	2	3	3	6	4	2	26

TABLE XIV.—*Correlation between egg weight and egg breadth in dwarf eggs with some yolk and not in a yolk membrane*

Egg breadth (in millimeters).	Egg weight (in grams).												
	3.00–5.99	6.00–8.99	9.00–11.99	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	30.00–32.99	33.00–35.99	36.00–38.99	Total.
18.00–19.99	1												1
20.00–21.99		3											3
22.00–23.99		3	1		1								5
24.00–25.99		1	11	5	1								18
26.00–27.99			5	27	3								35
28.00–29.99				2	13	8	2						25
30.00–31.99						4	11	4	1				20
32.00–33.99							2	9	5	2			18
34.00–35.99								2	3	1	3		9
36.00–37.99								1			2	1	4
Total	1	7	17	34	18	12	15	16	9	3	5	1	138

TABLE XV.—*Correlation between egg weight and egg breadth in dwarf eggs without yolk*

Egg breadth (in millimeters).	Egg weight (in grams).									
	3.00–5.99	6.00–8.99	9.00–11.99	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	Total.
18.00–19.99	1									1
20.00–21.99	1	2								3
22.00–23.99		3	3			1				7
24.00–25.99		1	5	1						7
26.00–27.99			2	7	6					15
28.00–29.99				1	14	7	1			23
30.00–31.99					1	7	8	2	2	20
32.00–33.99								3	3	6
34.00–35.99									1	1
Total	2	6	10	9	21	15	9	5	6	83

TABLE XVI.—*Correlation between egg weight and egg breadth in dwarf eggs with small yolks*

Egg breadth (in millimeters).	Egg weight (in grams).								
	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	30.00–32.99	33.00–35.99	Total.
26.00–27.99		1							1
28.00–29.99		4	1	1					6
30.00–31.99	1		1	2	1				5
32.00–33.99					2	3			5
34.00–35.99						2	4	1	7
36.00–37.99								1	1
38.00–39.99						1			1
Total	1	5	2	3	3	6	4	2	26

TABLE XVII.—*Correlation between egg weight and egg index in dwarf eggs with some yolk not in a yolk membrane*

Egg index (in percentage).	Egg weight (in grams).												
	3.00–5.99	6.00–8.99	9.00–11.99	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	30.00–32.99	33.00–35.99	36.00–38.99	Total
64.00–66.99	...	...	...	...	...	...	...	...	1	2	...	...	3
67.00–69.99	...	...	...	1	...	1	1	1	1	...	...	...	5
76.00–72.99	...	1	...	...	2	1	1	...	1	...	...	...	6
73.00–75.99	...	...	1	3	2	2	3	2	1	...	...	...	14
76.00–78.99	...	...	2	2	1	2	1	3	2	...	1	1	15
79.00–81.99	...	2	...	3	3	2	5	3	1	1	1	...	21
82.00–84.99	...	1	3	10	5	3	2	3	1	...	3	...	31
85.00–87.99	...	...	8	7	3	...	2	4	1	...	...	...	25
88.00–90.99	...	2	2	3	2	1	...	...	...	...	...	...	10
91.00–93.99	1	1	1	4	...	...	...	...	...	...	...	...	7
94.00–96.99	...	...	...	1	...	...	...	...	...	...	...	...	1
Total	1	7	17	34	18	12	15	16	9	3	5	1	138

TABLE XVIII.—*Correlation between egg weight and egg index in dwarf eggs without yolk*

Egg index (in percentage).	Egg weight (in grams).									
	3.00–5.99	6.00–8.99	9.00–11.99	12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	Total.
64.00–66.99	...	...	...	...	...	...	...	...	1	1
67.00–69.99	...	...	...	...	...	...	...	...	2	2
70.00–72.99	...	...	1	...	1	...	1	...	...	3
73.00–75.99	...	1	1	2	2	4	2	3	1	16
76.00–78.99	1	1	1	...	4	1	2	...	1	11
79.00–81.99	...	1	1	2	3	4	...	1	...	12
82.00–84.99	...	1	2	2	4	6	1	1	...	17
85.00–87.99	...	1	1	2	4	...	3	...	1	12
88.00–90.99	1	...	3	1	1	...	...	...	...	6
91.00–93.99	...	1	...	...	1	...	...	...	...	2
94.00–96.99	...	...	...	...	1	...	...	...	...	1
Total	2	6	10	9	21	15	9	5	6	83

TABLE XIX.—*Correlation between egg weight and egg index in dwarf eggs with small yolks*

Egg index (in percentage).	Egg weight (in grams). 12.00–14.99	15.00–17.99	18.00–20.99	21.00–23.99	24.00–26.99	27.00–29.99	30.00–32.99	33.00–35.99	Total.
65.00–67.99		1		1					2
68.00–70.99									0
71.00–73.99						1			1
74.00–76.99					1		2		3
77.00–79.99			1	1	1	4	2	1	10
80.00–82.99		3	1	1					5
83.00–85.99	1	1			1	1		1	5
Total	1	5	2	3	3	6	4	2	20

Table XX shows the correlation coefficients deduced from Tables VIII to XIX (or in the case of yolk weight from the data) with their probable errors, and also similar coefficients for normal eggs. The correlations are all calculated from the usual Bravais formula

$$r = \frac{S(xy)}{N\sigma_1\sigma_2}$$

where N = number of eggs; x and y are the deviations from the means and σ_1 and σ_2 the standard deviations of the two variables.

TABLE XX.—*Correlation coefficients for the size and shape characters of the dwarf and normal eggs*

Kind of eggs.	Number of eggs.	Correlation coefficients. Length and breadth.	Length and weight.	Breadth and weight.	Index and weight.	Yolk weight and egg weight.	Yolk weight and albumen weight.
Free-yolked dwarf	138	0.874±0.013	0.933±0.007	0.950±0.006	0.408±0.045		
Yolkless dwarf	83	.844± .021	.924± .011	.919± .011	−.368± .064		
Small-yolked dwarf	26	.759± .056	.840± .039	.883± .029	−.093± .131	[a]0.940±0.020	[a]0.789±0.064
Normal (mean of individual coefficients for 22 birds)	3,180	.378	.753	.830	−.185	.818	.566
Normal (eggs laid by flock on a single day)	450	.084± .032	.580± .022	.836± .010	.085± .032		

[a] These coefficients were calculated directly from the data given in Table III.

Table XXI gives the differences between various of these correlation coefficients, the probable error of the differences, and the ratio of each difference to its probable error.

TABLE XXI.—*Deviation in correlation coefficients, the probable error of the differences, and the ratio of each difference to its probable error*

Class of eggs.	Pairs of characters, the correlation coefficients of which are compared.	Difference in correlation coefficients with probable error.	Difference ÷ probable error of difference.
Free-yolked dwarf	Breadth with weight—length with weight	0.017±0.009	2.0
Do	Length with weight—length with breadth	.059± .015	3.9
Do	Length with breadth—index with weight	.466± .050	9.3
Yolkless dwarf	Breadth with weight—length with weight	−.005± .016	.3
Do	Length with weight—length with breadth	.080± .024	3.3
Do	Length with breadth—index with weight	.476± .067	7.1
Small-yolked dwarf	Breadth with weight—length with weight	.043± .049	.9
Do	Length with weight—length with breadth	.081± .068	1.2
Do	Length with breadth—index with weight	.667± .142	4.7
Normal	Breadth with weight—length with weight	.256± .023	11.1
Do	Length with weight—length with breadth	.496± .038	13.1
Do	Length with breadth—index with weight	−.001± .045	.02

Pairs of characters correlated.	Classes compared.	Difference in correlation coefficients with probable error.	Difference ÷ probable error of difference.
Length with breadth	Free-yolked—yolkless	0.030±0.025	1.2
Do	Yolkless—small-yolked	.085± .060	1.4
Do	Small-yolked—normal	.675± .065	10.4
Length with weight	Free-yolked—yolkless	.009± .013	.7
Do	Yolkless—small-yolked	.084± .041	2.1
Do	Small-yolked—normal	.260± .044	5.9
Breadth with weight	Free-yolked—yolkless	.031± .013	2.4
Do	Yolkless—small-yolked	.036± .031	1.2
Do	Small-yolked—normal	.047± .031	1.5
Index with weight	Free-yolked—yolkless	.040± .080	2.5
Do	Yolkless—small-yolked	.276± .146	1.9
Do	Small-yolked—normal	.007± .135	.05
Yolk weight with egg weight.	do	.122	....
Yolk weight with albumen weight.	do	.223	....

From Table XX the following points may be noted:

1. In each class of dwarf eggs the correlation between the two dimensions is positive and is certainly significant—that is, a broad dwarf egg is also long, and vice versa. The shape of the egg is no doubt determined by the action of the longitudinal and circular muscle fibers of the oviduct walls, especially during the formation of the egg membrane and shell. The egg is a fluid body which tends to take a spherical shape when not under pressure. At the time an egg receives its membrane and shell a normal egg or almost any dwarf egg is larger than the normal diameter of the oviduct. It is therefore under pressure which tends to elongate it in the direction of the long axis of the duct. The degree of pressure and, hence, the resulting degree of elongation will depend on (a) the size of the egg compared to the diameter of a cross section of the duct, and

(b) the relative tonus of the two sets of muscle fibers of the oviduct wall. A decrease in the tonus of the circular fibers, or an increase in that of the longitudinal fibers, or both, may counterbalance the increase in pressure due to increase in the diameter of the egg. There is no a priori reason for assuming a correlation between breadth and length; in fact, this correlation was not significant in the random sample of normal eggs studied by Pearl and Surface (20). From this they concluded that the two sets of muscles are to a large extent independent in their action. On the other hand, Curtis (4) found that within the normal eggs of an individual there is usually [1] a significant correlation between length and breadth—that is, the size of the active oviduct and relative tonus of the two sets of muscle fibers in the oviduct wall are apparently usually relatively stable in an individual, and an increase in the breadth of the egg is correlated with an increase in the length. The fact that the correlation between length and breadth is significantly higher (Table XXI) for dwarf eggs than for normal eggs may indicate that in these small eggs there is little or no differential stimulus on the muscle fibers of the oviduct wall, but that there is such a stimulus when the egg is larger.

2. Length and breadth are both highly correlated with weight—that is, a heavy egg is both broad and long. These relations are also true for normal eggs. The random sample of eggs studied by Pearl and Surface (20) showed a correlation between breadth and weight which was significantly higher than the correlation between length and weight. The individual birds studied by Curtis (4) showed a great variation in the relative degree of correlation of the two dimensions with the weight. Half the flock showed a correlation for breadth and weight significantly higher than for length and weight. Two birds showed a higher length-weight correlation. For one-third of the flock the difference was insignificant. There is no significant difference between breadth-weight and length-weight correlation in any class of dwarf eggs. (See Table XXI.)

3. The index-weight correlations are negative, and they are significant for dwarf eggs with little or no yolk—that is, for those two groups of small dwarf eggs the larger the egg the longer it is in proportion to its breadth. In the study of the normal eggs of individual birds Curtis (4) found that there was a low negative correlation between index and weight which was significant for one-half of the individuals studied. This tendency toward a negative correlation between index and weight in dwarf and normal eggs is in line with the fact that the mean index of the several groups of dwarf eggs, normal eggs, and multiple-yolked eggs varies in the opposite direction from the mean egg weight of each group—that is, the larger the egg the lower the index. The bearing of this fact has already been discussed.

[1] In 18 out of 22 individuals studied.

4. The correlation between yolk weight and egg weight in dwarf eggs with small yolks is very high. Since the yolk weight forms part of the egg weight, we will confine our discussion to the correlation between yolk weight and albumen weight. This correlation is also very high. It is in fact higher than the average correlation between yolk weight and albumen weight within the normal eggs of a single individual. This high correlation between yolk weight and albumen weight in dwarf eggs with small yolks adds to the evidence already presented that the amount of yolk present in the duct is an important factor in determining the amount of albumen secreted, and thus both directly and indirectly influences the size of the egg.

V.—FREQUENCY OF THE OCCURRENCE OF DWARF EGGS COMPARED TO NORMAL EGGS AND OF DWARF EGG PRODUCERS COMPARED TO BIRDS WHICH DO NOT LAY DWARF EGGS.

As previously stated, the period covered by this investigation extends from February 1, 1908, to February 1, 1916. During this period it has been the practice to make up the flock in September or early October. A few of the birds of the previous flock are saved for specific experiments and the rest killed or sold. The pullets are put in the houses at this time. The 298 dwarf eggs collected were thus produced by nine different flocks of birds. The number laid by each flock is given below:

	Number of dwarf eggs.
Feb. 1, 1908, to Aug. 31, 1908	16
Sept. 1, 1908, to Aug. 31, 1909	20
Sept. 1, 1909, to Aug. 31, 1910	34
Sept. 1, 1910, to Aug. 31, 1911	43
Sept. 1, 1911, to Aug. 31, 1912	59
Sept. 1, 1912, to Aug. 31, 1913	17
Sept. 1, 1913, to Aug. 31, 1914	27
Sept. 1, 1914, to Aug. 31, 1915	72
Sept. 1, 1915, to Feb. 1, 1916	10
Feb. 1, 1908, to Feb. 1, 1916	298

The first and last years are, of course, incomplete. The fluctuations between the other years are no doubt due largely to three causes. First, the size of the flock differs somewhat from year to year. Second, the average annual egg production fluctuates with changes in the proportion of low and high laying strains which compose the successive flocks—for example, the 1914–15 flock contained 55 less birds than the 1911–12 flock, and at the same time produced 25,374 more eggs, so that although it produced 22 per cent more dwarf eggs, the proportion of these eggs to the normal eggs was smaller. Third, as will be discussed later, certain birds suffer disturbances of physiology which cause them to produce a number of dwarf eggs. Such birds do not occur every year; in fact, an unusual proportion of the known cases occurred during the two years of highest dwarf-egg pro-

duction—that is, 1911–12 and 1914–15. During any year a few dwarf eggs may have escaped collection by being broken in the nest or laid on the floor and lost in the litter. This loss can not have been large at any time. However, in order to avoid the possibility of an unequal loss during the several years, the two years of highest dwarf-egg production were selected for a comparison as to the frequency of dwarf and normal eggs.

The frequency of the occurrence of dwarf eggs compared to normal eggs may be determined by calculating the percentage of all the eggs produced which are dwarf. For convenience this percentage may be multiplied by 100. This number represents the number of dwarfs in 10,000 eggs. This percentage was calculated for each of the 12 months of the two years taken both separately and combined. These data are given in Table XXII.

TABLE XXII.—*Total egg production, dwarf-egg production, and number of dwarf eggs per 10,000 eggs for each month of the years 1911–12 and 1914–15 both separately and combined, also for the two years combined the percentage of all the eggs and of all of the dwarf eggs which were produced during each calendar month*

Month.	1911–12			1914–15			1911–12 and 1914–15 combined				
	Total eggs.	Dwarf eggs.	Dwarf eggs per 10,000 eggs.	Total eggs.	Dwarf eggs.	Dwarf eggs per 10,000 eggs.	Total eggs.	Dwarf eggs.	Dwarf eggs per 10,000 eggs.	Percentage of total number of eggs produced during month	Percentage of total number of dwarf eggs produced during month.
September....	1,870	2	10.7	694	1	14.4	2,564	3	11.7	1.69	2.29
October......	2,940	1	3.4	2,589	0	.0	5,529	1	1.8	3.64	.76
November.....	2,773	2	7.4	3,771	6	15.9	6,494	8	12.3	4.27	6.11
December.....	4,501	2	4.4	5,416	3	5.5	9,917	5	5.0	6.54	3.82
January......	4,429	2	4.5	7,131	4	5.6	11,560	6	5.2	7.62	4.58
February.....	4,375	0	.0	8,409	3	3.5	12,784	3	2.3	8.43	2.29
March........	9,407	7	7.4	9,728	5	5.1	19,135	12	6.3	12.61	9.16
April........	7,886	7	8.9	11,406	8	7.0	19,292	15	7.8	12.71	11.45
May..........	7,738	10	12.9	11,051	7	6.3	18,789	17	9.0	12.38	12.98
June.........	7,121	17	23.9	10,080	10	9.9	17,201	27	15.7	11.34	20.61
July.........	5,539	2	3.6	9,618	20	20.7	15,157	22	14.5	9.99	16.79
August.......	4,657	7	15.0	8,667	5	5.7	13,324	12	9.0	8.78	9.16
Total....	63,176	59	9.3	88,560	72	8.1	151,736	131	8.6	100.0	100.0

The last line in Table XXII shows the total number of eggs, the total number of dwarf eggs, and the number of dwarf eggs per 10,000 for each of the two years, and for the two years combined. From these data it is seen that during the year 1911–12 the flock produced 59 dwarf eggs out of a total of 63,176, or 9.3 dwarf eggs in 10,000—that is, 1 dwarf egg in each 1,071 eggs. In 1914–15 the flock produced 72 dwarf eggs in a total of 88,560 eggs—that is, 8.1 dwarf eggs in 10,000, or 1 dwarf to 1,230 eggs. If the data for the two years are combined, there were produced 131 dwarf eggs in 151,736 eggs—that is, during the two years of maxi-

mum dwarf-egg production the proportion of dwarf to normal eggs was 8.6 dwarf eggs in 10,000, or 1 dwarf egg in 1,158 eggs. Warner and Kirkpatrick (26) show that during two laying contests at Storrs, Conn., 199,137 eggs were produced, of which 103 weighed less than 0.09 pound (40.82 gm.). From these figures we see that they obtained 5.2 dwarf eggs per 10,000, or 1 dwarf in 1,933 eggs.

The nine flocks which laid the dwarf eggs considered in this investigation contained approximately 4,800 different individual birds. Not all of these birds had an equal opportunity to lay a dwarf egg, for while a large majority of them were kept until, and only until, the end of their pullet year, a number died at varying ages and a number were kept for more than one year. Also the records for 1907–8 and 1915–16 are incomplete. We may, however, arrive at an approximate estimate of the proportion of birds which lay one or more eggs by neglecting these discrepancies and considering that each of the 4,800 individuals had an equal opportunity to produce dwarf eggs.

The 251 dwarf eggs of known origin were produced by 200 different individuals. There were 47 eggs laid by birds whose number was not known. Most of these were floor eggs. In a very few cases the poultryman neglected to record the number of the bird on the egg at collection time, and in a very few others the trap-nest record of the bird laying the dwarf egg was lost through some other slip. Since most of the dwarf eggs of known origin were produced each by a different individual, we shall arrive at the fairest estimation of the number of birds which produce dwarf eggs by considering that each of these 47 was laid by a different individual, and by one which had not produced one of the dwarf eggs of known origin—that is, we may consider that the 298 eggs collected were produced by 247 individuals. From the above considerations it appears that during the last eight years at the plant of the Maine Station 247 out of 4,800 birds, or 5.15 per cent, produced at least one dwarf egg.

By means of the data given by Warner and Kirkpatrick (26) we may also approximate the relative number of dwarf-egg producers among the birds in the third and fourth laying contest at Storrs, Conn. These birds also did not all have an equal chance, since the data were worked up after 7 of the 12 months of the fourth contest. During these contests 85 out of 1,820 birds, or 4.67 per cent, laid one or more dwarf eggs. If the data had been digested after the fourth contest had been completed, it is quite probable that a few more birds would have laid dwarf eggs—that is, the percentage given may be too low.

The close agreement of the two approximations indicates that about 5 per cent of the birds in an average flock will produce at least one dwarf egg.

VI.—SEASONAL FREQUENCY OF DWARF EGGS COMPARED TO NORMAL EGGS

Dwarf eggs are frequently found by poultrymen during the spring and early summer and somewhat less frequently at other seasons. During the eight years that these eggs have been collected at the plant of the Maine Station they have occurred during every one of the 12 months. However, 70.8 per cent of them were laid during the five months from March 1 to July 31. During some years more than 80 per cent were produced during these months. Table XXIII gives the number of dwarf eggs produced each month for each of the eight years. It gives also the percentage of all of the dwarf eggs which were produced during each calendar month and the monthly percentage of the annual egg yield as determined by Pearl and Surface (19) for the years 1899 to 1907.

TABLE XXIII.—*Number of dwarf eggs recorded each month from February 1, 1908, to February 1, 1916, and the percentage of the total number of dwarf (1908–1916) and normal (1899–1907) produced during each calendar month*

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Total
1907 and 1908						1	1	5	5	4	0	0	[a] 16
1908 and 1909	0	0	0	0	0	3	7	5	1	3	0	1	20
1909 and 1910	2	1	1	0	0	3	7	5	5	0	10	0	34
1910 and 1911	0	1	2	3	1	2	3	3	12	6	4	6	43
1911 and 1912	2	1	2	2	2	0	7	7	10	17	2	7	59
1912 and 1913	1	1	1	1	3	0	1	0	7	1	1	0	17
1913 and 1914	0	3	0	0	2	0	4	8	4	5	1	0	27
1914 and 1915	1	0	6	3	4	3	5	8	7	10	20	5	72
1915 and 1916	0	5	2	2	[b] 1								[a] 10
Total	6	12	14	11	13	12	35	41	51	46	38	19	208
Percentage of total number produced during month	2.01	4.03	4.71	3.69	4.36	4.03	11.74	13.76	17.11	15.44	12.76	6.36	100
Percentage of total annual yield of normal eggs produced during month (1899–1907)	[c] 6.36	[c] 4.27	3.59	6.91	9.08	8.44	12.50	12.30	10.80	9.67	8.44	7.64	100

[a] Years incomplete.
[b] Calculations in earlier parts of paper were completed before this egg was laid.
[c] These should follow August, as they are for the end and not the beginning of the year.

The more frequent occurrence of dwarf eggs during the spring and summer is seen either in the record for each year or in the sums at the foot of Table XXIII. It must be kept in mind that this is the natural breeding season of the fowl and that the total number of eggs laid during these months is greater than during the other months of the year. Whether or not the number of dwarf eggs in the breeding season is greater than is to be

expected if they occur in a given ratio to normal eggs can only be decided by a comparison of the production of dwarf eggs with the normal-egg production.

The monthly distribution of normal-egg production has been investigated thoroughly in the Maine Station flock by Pearl and Surface (19). Their investigations cover the eight years preceding the beginning of the present study. They summarized their data for the whole period by obtaining the percentage of the total yearly egg production which occurred during each month. This egg-production polygon may be used as a basis for a rough comparison between the relative seasonal frequency of dwarf and normal eggs. Figure 1 shows this egg-production polygon and a similar polygon showing for the eight years of the present investigation

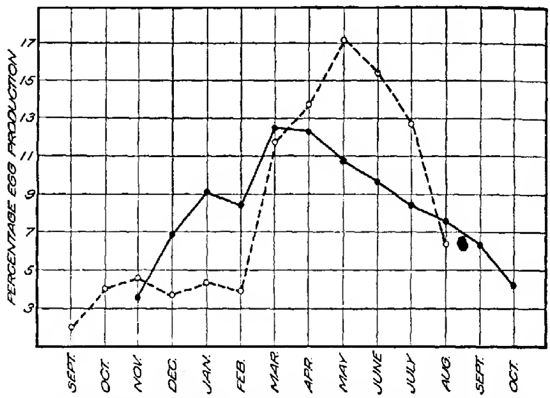

FIG. 1.—Diagram showing the percentage of the yearly total egg production (8-year average, 1899–1907) and the percentage of the total dwarf-egg production (8-year average, 1908–1916) which occurred during each month. Solid line=percentage of annual egg production. Dash line=percentage of annual dwarf-egg production.

the percentage of all of the dwarf eggs which were produced during each month. The data are given in the last two lines of Table XXIII. It will be noted that the two polygons do not begin or end with the same month. The reason for this is that the first set of data was collected for September and October after the birds were a year old, while, as already stated, during the period covered by the second investigation the data from September 1 to September 1 represent more nearly the data on a single group of birds.

From the diagram it is seen, as would be expected on the theory of chance, that during the months of heaviest normal-egg production more dwarf eggs are produced than at other seasons. Yet it is also seen that the two curves are by no means parallel. The egg-production curve rises

gradually through the fall and winter to its spring maximum and then drops away even more gradually. The dwarf-egg production curve does not rise during the fall and winter, but rises very abruptly during the spring to its maximum, which is three months later than the maximum for the normal-egg curve. It remains relatively higher than the normal curve through the early summer.

Since the data for the two polygons are derived from entirely different birds, it is desirable to pursue the investigations further and compare the

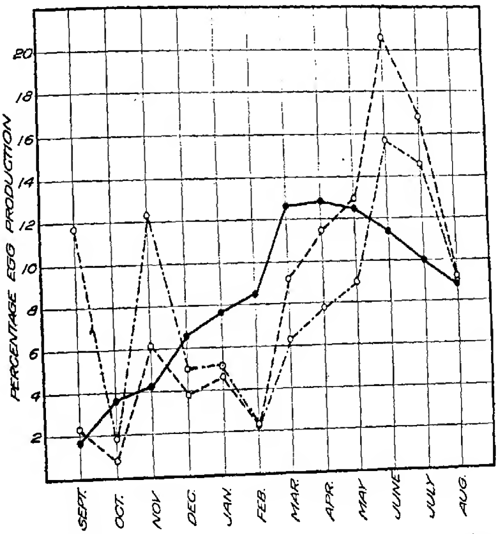

FIG. 2.—Diagram showing for the years 1911–12 and 1914–15 combined the percentage of the yearly total egg production and dwarf-egg production which occurred during each month and 100 times the percentage of the eggs produced each month which were dwarf. Solid line = percentage of total yearly egg production per month. Dash line = percentage of total yearly dwarf-egg production per month. Dot-dash line = the percentage (× 100) of dwarf eggs produced during the month.

number of dwarf eggs and the number of normal eggs produced by the same birds. The two years of maximum dwarf-egg production, 1911–12 and 1914–15, were selected for this study. The data for this study are given in Table XXII, which shows the total egg production, the dwarf-egg production, and the number of dwarf eggs per 10,000 eggs for each month of the two years. The last five columns of the table give the data for the two years combined. The summary data given in the last three columns are shown graphically in figure 2.

An examination of the diagram or of the data given in Table XXII shows that not only is the actual number of dwarf eggs smallest during the winter but that the number of dwarf eggs per 10,000 is also smallest. The irregular fluctuations of the fall are due to the fact that three of the abnormal birds already referred to laid during these months. The small number of normal eggs produced at this season gives great weight to these dwarf eggs in calculating the number of dwarf eggs per 10,000. Both the actual number of dwarf eggs and number per 10,000 increases through the spring, reaching its maximum in early summer some months later than the maximum for normal-egg production. It is thus shown that the dwarf-egg production is actually highest and also highest in proportion to the normal-egg production during the spring and early summer.

It thus seems probable that the disturbances in physiology which result in the production of dwarf eggs become more frequent with the onset of the natural breeding season and continue to increase in frequency during this season. The probable nature of these disturbances will be discussed later.

VII.—DWARF EGG PRODUCTION BY BIRDS WITH NORMAL AND WITH PATHOLOGICAL OVIDUCTS

The production of a dwarf egg is usually an isolated phenomenon—that is, a bird usually produces only one such egg. This fact, which has already been noted, is easily seen from Table XXIV.

TABLE XXIV.—*Number of dwarf eggs laid by each bird which produced one or more such eggs*

Number of dwarf eggs laid by a bird.	Number of birds.	Percentage of birds.	Number of eggs.
1	178	89.0	178
2	15	7.5	30
3	3	1.5	9
4	1	0.5	4
5	1	0.5	5
8	1	0.5	8
17	1	0.5	17
Total	200	100.0	251
Number of dwarf eggs laid by birds whose number was not known—that is, mostly floor eggs			47
Total			298

From Table XXIV we see that of the 200 birds which produced one or more dwarf eggs, 178, or 89.0 per cent, produced only one; 15, or 7.5 per cent, produced two; and only 7, or 3.5 per cent, more than two. The figures given by Warner and Kirkpatrick (26) for the birds in the Connecticut Station laying contest show an even larger percentage (94.11 per cent) of the dwarf-egg producers which lay only one dwarf egg. One

bird laid 14 dwarf eggs and no normal eggs. Each of the four others (4.71 per cent) laid two. It is thus apparent that the production of dwarf eggs is not usually an evidence of a permanent abnormality or derangement of the reproductive organs. This view is strengthened by a study of the egg records for the birds which produced dwarf eggs. In almost all cases these birds have a normal egg record. The dwarf egg is preceded and followed by normal eggs quite as though it was a normal egg. Autopsies were performed on several such birds, some immediately after the production of the dwarf egg. The sex organs were morphologically normal. There were, however, 11 of the 200 which showed evidence of a permanent disturbance, since few or no normal eggs were produced after the dwarf egg or eggs. In most of these cases the bird made nesting records. It has been shown by the authors (6,13) that "nesting records are, in the great majority of cases, at least, associated with ovulation into the body cavity or the backing into it of partly or fully formed eggs." Furthermore, autopsies were made on 5 of the 11 cases and all of these showed pathological conditions of the oviduct which would interfere with the passage of the egg but which did not entirely close the duct. These cases will be discussed in detail later. The point with which we are at present concerned is that the records for only 11 (5.5 per cent) of the 200 birds showed evidence of a permanent disturbance of the egg-forming processes. It is then evident that the disturbance which causes the production of a dwarf egg is usually of an accidental or at least temporary nature. However, there are certain pathological conditions of the oviduct which result in the formation of a dwarf egg instead of a normal egg.

The 11 cases where dwarf egg production appeared to be related to a permanent disturbance of the physiology of the sex organs include all of cases where the bird produced more than three dwarf eggs, two that produced three, one that produced two, and four that produced only one dwarf egg. The production of a succession of dwarf eggs or of a long series of nesting records with one or two dwarf eggs should lead one to suspect a serious disturbance of the oviduct.

We will first consider dwarf-egg production which is not associated with a morphological abnormality of the sex organs and will then discuss the pathological cases.

VIII.—THE RELATION OF DWARF-EGG PRODUCTION BY NORMAL BIRDS TO THE AGE OF THE BIRD AND TO THE POSITION OF THE EGG IN THE LITTER AND CLUTCH

A.—AGE

Attention has already been called to the fact that while dwarf eggs may be produced at any season of the year the spring breeding season, the season for highest normal-egg production, is also the season for highest

dwarf-egg production, both in actual number of dwarf eggs and in the proportion of dwarf to normal eggs produced. It was, however, shown that the maximum dwarf-egg production (either absolute or relative) did not coincide with the maximum normal-egg production.

Earlier studies (5) have shown a decided relation between the age of the bird and the tendency to produce multiple-yolked eggs—that is, birds are more likely to produce double- or triple-yolked eggs before they are entirely mature than later in life. In this connection it seemed worth while to investigate a possible relation between dwarf-egg production and age.

There were 189 normal[1] birds which laid one or more dwarf eggs. These birds laid 205 dwarf eggs. The age of the bird at the time the dwarf egg was laid could be determined in 202 cases. The age frequency distribution is given below.

Age in days.	Dwarf-egg frequency.	Age in days.	Dwarf-egg frequency.
150–209	11	690–749	6
210–269	14	750–809	2
270–329	22	810–869	2
330–389	65	870–929	0
390–449	52	930–989	0
450–509	19	990–1,049	1
510–569	4	1,050–1,109	1
570–629	0		
630–689	3		202

The constants calculated from this frequency distribution are: Mean = 396.53 ± 6.43 days; standard deviation = 135.57 ± 4.55 days; and coefficient of variation 34.19 ± 1.27. These constants must not, however, be accepted as a description of the age variation. It has already been noted that a large proportion of the birds are disposed of at the end of their first laying year—that is, when they are 15 to 17 months of age. There were, therefore, many more chances for a bird to lay a dwarf egg during her first year than later in life. From data in hand it is not possible to decide whether or not a bird is more likely to lay a dwarf egg during the second or third year than during the pullet year. The flocks were not depleted, however, except by the normal small mortality from natural causes, until the end of the first laying year. It may be noted from the distribution that pullets are increasingly likely to lay dwarf eggs up to the time they are 1 year old and that the chances then decrease up to the end of the pullet year. The mean age for dwarf-egg production among pullets may be calculated from the above distribution as far as and including the 450–509-day group. This mean is 361.96 ± 3.75 days, approximately 1 year. It is apparent also that the second year maximum falls in the 690–749-day group—that is,

[1] That is, a complete study of their records, checked in many cases by post-mortem examinations, showed no abnormality.

when the bird is approximately 2 years old. Dwarf eggs are also produced by birds approximately 3 years old. From these data we see that dwarf egg production, unlike multiple-yolked-egg production, is not associated with immaturity of the bird, but that it is most likely to occur during the height of the breeding seasons in the successive years. These are, of course, the seasons of highest normal-egg production. In the case of a very few of the young birds and in an appreciable percentage of the old birds this is the only season in which the birds are in laying condition.

B.—POSITION IN THE LITTER

There is a widespread popular belief that a dwarf egg marks the end of a laying period or litter. This belief has found frequent expression in the literature from an early period to the present day. König-Warthausen (7) summarizes the belief of Tiedemann (25) as follows: "Er hält die dotterlosen Zwergeier für 'Reste von in Eileiter abgesondertem Eiweiss und Kalkerde' nachdem durch Jahreszeit oder Alter das Legen zu Ende ist." To this, however, he adds his own observation, "dass solche Fehlgeburten vielfach bei erstlegendern Hühnern (in meiner Sammlung aus Marz, April, und Mai) stattfinden." Wright (28, p. 579), in his discussion of normal eggs, says: "Of the other kinds of abnormal eggs the very small ones only containing albumen usually occur at or near the end of a batch of eggs." That this relation of the occurrence of a dwarf egg to a particular position in the litter is still somewhat generally accepted is shown by two recent statements. Lewis (9) says that "extremely small eggs are common at the beginning and end of a laying period." The second statement referred to occurs in an unsigned article on "Xenia in fowls" in the Journal of Heredity (29) and is as follows:

Experiments during recent years show that the eggs of any individual hen tend to become a little smaller as she approaches the end of her laying period, and the last one, it is generally believed, is likely to be a dwarf.

Since both dwarf eggs and broody hens are most common during the breeding season, it is not unnatural that a relationship between the two is assumed by poultrymen who do not trap-nest their birds. The use of the trap nest, however, soon dispels this illusion. Pearl, Surface, and Curtis (21) say that "the laying of one of these eggs is popularly supposed to mark the end of a laying period. This belief is without foundation in fact. They may be produced at any time." Warner and Kirkpatrick (26) some years later arrived at the same conclusion after a study of the data collected during two laying contests at Storrs. They summarize their data on this point as follows:

It was found that only two eggs out of a total of 103 indicate a resting period after the production of a small egg. In every other case the small egg was found in an

almost uninterrupted series of normal eggs. This seems to prove conclusively that small eggs may be laid at any time during a hen's laying period and that most small eggs are laid while hens are at the height of production.

The data used in the present investigation confirm the main part of this statement—that is, dwarf eggs may be produced at any time during the laying period. Our figures do not show that they are less likely to be produced at either end of the period than during its midst, as the above authors seem to imply by their statement that "most small eggs are laid while hens are at the height of production." It is quite possible that they do not intend to make such an inference. Their records show that out of 103 eggs 7 were laid after a resting period of 14 to 25 days and 2 were followed by such a resting period. Our own records for normal birds which produced dwarf eggs and which completed the period of production during which the dwarf egg was laid show that out of 183 dwarf eggs 8 were first and 11 last eggs in their respective litters. A further analysis of our data on the position of the dwarf egg in the litter follows.

A few birds lay practically continuously from the beginning of laying until the first molt. Usually, however, there are well-defined laying periods which alternate with periods of nonproduction. The periods of production vary in extreme cases from two weeks to several months. In the present investigation any period of practically continuous laying, whatever its length, is considered a litter. In order to determine the relation of the production of a dwarf egg to its position in the litter, it is necessary to standardize the litter for the purpose of summarizing the data from the different cases. If the ordinal number of the day in the production period be divided by the whole number of days in the period, the resulting fraction will represent the position in the litter of an egg produced on that day. By this method the litter position of each dwarf egg produced by a normal bird which completed the litter was obtained. The frequency distribution for litter position of dwarf eggs is given below.

Fraction of litter.	Dwarf-egg frequency.
0 -0.099	26
.100- .199	19
.200- .299	10
.300- .399	16
.400- .499	13
.500- .599	21
.600- .699	24
.700- .799	15
.800- .899	10
.900- .999	29
	183

Mean = 0.506 ± 0.015

Standard deviation = 0.307 ± 0.011

This distribution is shown graphically in figure 3. It does not show a tendency of a dwarf egg to be produced at any particular position in the litter—that is, the variation in the class frequencies are irregular. The dash line in the figure represents the mean class frequency; in other words, it represents graphically the frequency distribution for 183 observations evenly distributed among 10 classes. It is the ideal distribution of things equally likely to fall into any one of the 10 classes.[1] The question which concerns us is whether or not the actual distribution differs from this ideal distribution by an amount greater than we would expect if the differences are due entirely to errors in sampling.

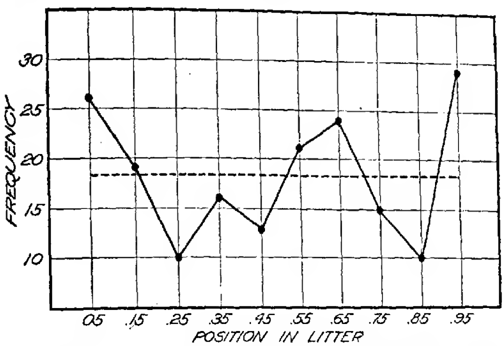

FIG. 3.—Diagram showing the number of dwarf eggs which occurred in each tenth of a litter. Dash line= the mean frequency.

A frequency curve of a given area is defined by its mean and the moments about this mean. The first four moments or the three constants, standard deviation, β_1 and β_2, derived from these moments define a curve sufficiently for practical purposes. Two frequency curves of equal area which differ significantly from each other will show a significant difference between one or more of the similar constants. These constants and also the mean, which gives the location of the curve in space, were computed for both the actual and the ideal distribution. These constants, with their probable errors, and the difference between the similar constants for the two curves, with the probable error of difference, are given in Table XXV.

[1] A general treatment of this " horizontal line " frequency curve, which is a special case of Pearson's Type II, will shortly be published elsewhere.

TABLE XXV.—*Mean standard deviation, β_1, β_2, and the difference between the similar constants for the two distributions for the actual frequency distribution of the position of dwarf eggs in the litter and for an ideal evenly distributed frequency of the same size* [a]

Distribution.	Mean.	Standard deviation.	β_1	β_2
Actual	0.506±.015	0.307±.011	0.003±.001	1.73±.05
Ideal	.500±.014	.287±.016	0	1.78±.06
Difference with probable error of difference	.006±.021	.020±.019	.003	.05±.08

[a] These constants are equal for any evenly distributed 10-class frequency with a class unit of 0.1, but the probable errors given in the table are calculated on the basis of 183 observations.

The last line of Table XXV shows that in no case does an essential constant for the actual curve differ from the similar constant for the ideal curve by an amount which is certainly significant—that is, the irregular fluctuations of the frequency curve for the litter position of dwarf eggs are not greater than the expected fluctuations of a random sample of the same size drawn from a population evenly distributed over the range. The present data, then, indicate that a dwarf egg is equally likely to occur at any time during a period of production.

C.—POSITION IN THE CLUTCH

A fowl seldom lays on every day during a litter. The actual time between successive eggs depends on the rate of fecundity of the individual at the time. This rate differs greatly with the individual and with the season of the year. It also, in general, increases from the beginning of a litter to a maximum and then decreases toward the end of the period of reproduction (4, 19). Since fecundity finds its manifestation in discrete units (eggs), the result of a very low rate is expressed by the production of an egg on a day preceded and followed by one to several days on which no egg is produced. A common low fecundity rhythm results in the production of an egg on every second day. More usually an egg is produced somewhat later on each of two or more successive days, and then a day follows on which no egg is produced. The next egg is produced early on the following day. The litter is thus objectively broken into a series of daily eggs, which we may call "clutches," separated by one or more days on which no egg is produced. The size of a clutch varies from one egg to the extreme and unusual cases where a whole litter (sometimes of more than 40 eggs) is laid in a continuous daily series.

The general acceptance of the notion that a dwarf egg marks the end of a period of production suggests an investigation of the position of the dwarf egg within its clutch. In 197 of the cases where a normal bird produced a dwarf egg the bird completed the clutch to which the dwarf

egg belonged. Table XXVI gives for every size of clutch the frequency distribution of clutch position of dwarf eggs.

TABLE XXVI.—*Clutch-position frequency of the dwarf eggs for every size of clutch*

Number of eggs in the clutch.	Ordinal number of the egg in the clutch.																
	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.	10th.	11th.	12th.	13th.	14th.	15th.	Total.	Percentage.
1	50	...	...	...	...	...	...	...	...	...	...	...	...	...	...	50	25.38
2	26	20	...	...	...	...	...	...	...	...	...	...	...	...	...	46	23.35
3	10	19	13	...	...	...	...	...	...	...	...	...	...	...	...	42	21.32
4	5	5	7	7	...	...	...	...	...	...	...	...	...	...	...	24	12.18
5	2	4	3	2	5	...	...	...	...	...	...	...	...	...	...	16	8.13
6	0	2	2	0	1	0	...	...	...	...	...	...	...	...	...	5	2.54
7	1	1	0	0	1	3	0	...	...	...	...	...	...	...	...	6	3.05
8	0	0	0	0	1	0	2	0	...	...	...	...	...	...	...	3	1.52
9	1	0	0	1	0	0	0	0	0	...	...	...	...	...	...	2	1.01
11	0	0	1	0	0	0	0	0	0	0	0	...	...	...	...	1	.51
15	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	1.01
Total	95	51	26	10	8	3	2	0	0	1	0	0	0	0	1	197	100.00

This table (XXVI) shows that 50 dwarf eggs occurred as 1-egg clutches—that is, no egg was produced on either the preceding or the following day. Forty-six occurred in 2-egg clutches, the other egg being in each case a normal egg. Of these, twenty-six were the first, and twenty the second, of the two eggs. Similarly through the table we may compare the number of dwarf eggs produced in the successive positions in a clutch of any given size. The clutches in which dwarf eggs occurred varied in size from one to fifteen eggs. A study of this table shows no apparent uniform tendency for a dwarf egg to occur in any particular position in a clutch.

In order to summarize the data for the various-sized clutches, it is necessary to standardize the clutch. A clutch may be conceived as a line of definite length. This line may be divided into as many segments as there are eggs in the clutch. Each segment may be assigned a value equal to the fraction which the distance from the origin to the midpoint of the segment is of the whole length of the line. An egg, then, has a definite clutch-position value expressed as a fraction of the clutch. These values are comparable for all sizes of clutches. For example, the value assigned to the middle egg of any clutch which contains an odd number of eggs is 0.500. A table was calculated which gives the value for each clutch position in each size of clutch. By means of this table the clutch position for each dwarf egg can be determined in terms which are comparable for all cases of dwarf-egg production whatever the size of the clutch.

The clutch-position fréquency for the occurrence of dwarf eggs is given below.

Fraction of clutch.	Dwarf-egg frequency.
0. -0.199	19
.200- .399	40
.400- .599	25
.600- .799	35
.800- .999	28
	147

Mean $=0.518 \pm 0.015$
Standard deviation $=0.267 \pm 0.011$

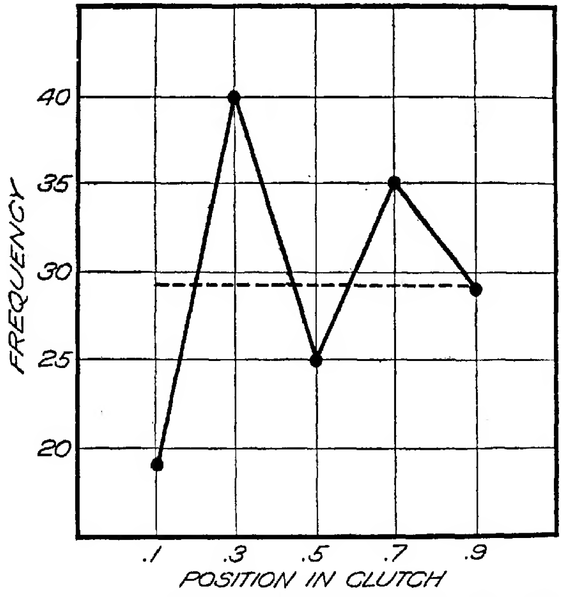

FIG. 4.—Diagram showing the number of dwarf eggs which occurred in each fifth of a litter. Dash line shows the mean frequency.

This distribution is shown graphically in figure 4.

There is no apparent relation of dwarf-egg production to any particular position in the clutch. The dash line in the figure, as in figure 3, represents an ideal uniform frequency for the same number of observations similarly grouped. In this case, as in the case of litter position, the actual frequency was tested against the ideal uniform frequency to determine whether or not the irregular fluctuations were greater than

would be expected from errors in sampling. The mean and the three constants which define frequency curves, standard deviation, β_1 and β_2, were calculated for the actual and the ideal distribution. It has already been pointed out that two distributions with the same number of observations which differ significantly will show a significant difference between the values for one or more of these similar constants. The constants for each distribution with the differences between the similar constants in the two curves are given in Table XXVII.

TABLE XXVII.—*Mean, standard deviation, β_1, and β_2, for the actual frequency distribution of the position of dwarf eggs in the clutch compared with the same constants for an equal even distribution with the same number of classes*

Distribution.	Mean.	Standard deviation.	β_1	β_2
Actual	0. 518±0. 015	0. 267±0. 011	0. 00005±0. 00003	1. 749±0. 051
Ideal	. 500± . 016	. 283± . 011	0	1. 700± . 054
Difference with probable error of difference	. 018± . 022	. 016± . 016	. 00005	. 049±. 076

The last line of Table XXVII shows that not one of these constants for the actual distribution differs significantly from the similar constant for the ideal distribution—that is, the irregular fluctuations in clutch position of dwarf eggs are not greater than would be expected to occur from errors of sampling. The present data indicate, then, that a dwarf egg is equally likely to occur in any clutch position.

IX.—PHYSIOLOGICAL CONDITIONS AND EFFECTIVE STIMULI WHICH LEAD TO DWARF-EGG PRODUCTION

It has been shown that dwarf eggs usually represent some temporary disturbance or some accident in the physiology of reproduction, since such eggs are preceded and followed by normal eggs. The disturbance is most likely to occur during the height of the breeding season, although it may happen at any time during the year. During any particular litter or clutch a dwarf egg is equally likely to occur at any time. Although the cause of dwarf-egg production is usually of a temporary character, there are cases where a bird lays only, or chiefly, dwarf eggs for some time. Other birds produce normal eggs for some time and then become habitual dwarf-egg producers. In the present section we will consider the nature of the disturbances, both temporary and permanent, which lead to the production of dwarf eggs.

Tiedemann (25) explained the origin of the dwarf eggs as the residue of albumen and shell secreted in the oviduct at the end of the laying. Wright (28) says that the occurrence of small abnormal eggs "need seldom

occasion anxiety. They usually occur at or near the end of a batch of eggs and merely show that the ovary is exhausting its supply of ova or yolks a little before the secreting parts of the oviduct are quite ready to suspend business." Lewis (8) explains dwarf-egg production, which he says is common at the beginning or end of a laying period, as "in part due to a diminution in the size, hence in the lessened secreting power of the oviduct." These views are untenable in the face of the facts cited above. Bonnet (2) says that such eggs mostly arise through pathological processes in the oviduct.

On the basis of unpublished data, Pearl, Surface, and Curtis (21, p. 176) made a statement of the factors which were probably involved in dwarf-egg production. The data on which this statement was based are included in the data used in the present investigations. The data then on hand indicated that three fundamental factors are concerned in dwarf-egg production. These are:

1. The bird must be in an active laying condition; the more pronounced the degree of physiological activity of the oviduct the more likely are these eggs to be produced.
2. There must be some foreign body, however minute, to serve as the stimulus which shall start the albumen glands secreting. This foreign body may be either a minute piece of hardened albumen, a bit of coagulated blood, a small piece of yolk which has escaped from a ruptured yolk, etc.
3. It seems likely, though this is a point not yet definitely settled, that ovulation—that is, the separation of a yolk from the ovary—must precede the secretion of albumen around the foreign body to form one of these eggs.

To a large extent the complete investigation confirms and extends these conclusions. The data which contribute to our knowledge of the physiology of dwarf-egg production are the complete egg records and the autopsy records of dwarf-egg producers.

A.—EVIDENCE FROM THE EGG RECORDS AND AUTOPSY RECORDS OF DWARF-EGG PRODUCERS WITH ABNORMAL SEX ORGANS

It has already been noted that the egg records for 11 of the 200 known dwarf-egg producers showed that few or no normal eggs were produced after the dwarf egg or eggs. Such birds usually make nesting records, the dwarf egg occurring in a series of the nesting records. As an illustration, the egg record of case 1 is given in Table XXVIII.

From this record it may be seen that the bird was a heavy layer, producing 162 eggs up to May 28. After this she produced only one normal egg (on June 26). The nesting records occurring in clutches indicate that the ovary passed through its normal cycles. Four dwarf eggs were produced in a series of nesting records. The bird made her last nesting record on January 16. Twenty-four days later (February 9) she was killed for data. She was in a normal healthy condition and was very fat. The visceral organs were apparently all perfectly normal, except the oviduct. The ovary contained an enlarging series of yellow yolks, four

of which were more than 1 cm. in diameter. There were no visible discharged follicles. The bird was evidently approaching another cycle of egg production. The oviduct was nearly the size of an oviduct in a laying bird of the same body weight. The organ had but one abnormality. Six cm. from the mouth of the funnel were two constrictions, separated by about 1 cm. of duct, with the same diameter as the rest of the albumen region. The finger could be pushed through these constrictions. There was no pathological appearance in the duct wall at these points. It seems probable, however, that these constrictions prevented the passage of the normal egg, but allowed the passage of a smaller body, as the beginning of the dwarf egg. No yolk was found in any of the dwarf eggs produced by this bird. The nucleus in each of three cases was one or more small lumps of coagulated albumen. The dwarf egg produced on November 21 contained a small-stalked hard-shelled dwarf egg. The entire egg weighed only 11.1 gm. Neither the outer nor inner egg contained any yolk.

TABLE XXVIII.—*Egg record of case 1.*[a]

Date.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Totals.
Sept.																n			n						n		1		1	1		
Oct.		1	1	1	1	1	1	1		1	1	1	n	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		27
Nov.	1		1		1	n	1	1	1	1	1	1	1	1	1	1		1		1	1	1	1	1	1	1	1	1	1	1		25
Dec.			1	1	1	1		1	1	1	1	1	1		1	1	1	1	1	1	1		1		1			n	n	1	1	21
Jan.		1	1	1		1	1		1	1		1	1	1		1		1	n	1		1			1	1		1		1		17
Feb.	1				1		1		1		1		1	n	1		1	n	1		1		1		n		1	1				13
																																107
Mar.		1		1		1		1	1		1	1		1	1		1	1	1		1	1	n	1		1	1	1	n	1		19
Apr.	1	n	1	1	1	1	n		1	1	1	n	1		1	1	n	1	1		1	1	1	1		1	n					18
May.	1	1		1	1	1	1	1	1	n	1		1		1	1	n		n	1		1	1	n	1	1		1				18
																																162
June.	n			n	n	n	n	n		n	n	n	n	n	n	n			n	n	n	n	n	n	n	1	n		n	n		1
July.	n	n	n	1–	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n	n			n	n	n	n	n	n	n	n	n	1–
Aug.	n	n	n	n	n	n		n	n	n	n	n	n	n		n		n	n	n	n	n	n	n								0
Sept.											n	n	n	n	n	n	n	n	n	n		n	n	n	n	n		n		n		0
Oct.																																0
Nov.										n	n		n	n	n	n			n		1–	n		1–		1–	n		n	n		3–
Dec.																	n															0
Jan.	n			n	n	n						n		n		n																0
Feb.									D																							

[a] "1" denotes a normal egg, "1-" a dwarf egg, "n" a visit to the trap nest but no egg, and "D" date killed for data.

Case 2 was that of another good layer which suffered a permanent disturbance, which hindered the production of normal eggs, but permitted dwarf-egg production. The case history of this bird follows. She began to lay on September 3, 1913. From this time until she stopped laying for the first molt, on October 5, 1914, she laid 218 eggs. On November 6, 1914, while the bird was still in nonlaying condition, three-fourths of her ovary was removed by a surgical operation. She began to lay again on December 29, 1914, and from this time until July 8, 1915, she produced 128 eggs. Three days later, July 11, she produced a dwarf egg. This was the first of a series of 7 dwarf eggs, the last of which was produced on July 23. Then followed an 8-day nonproductive period followed by a clutch of 3 normal eggs, on July 31 and Au-

gust 1 and 2. These were the last normal eggs produced. One more dwarf egg was produced on August 7. On August 29 the bird died of peritonitis.

At the autopsy a cylindrical dwarf egg was found in the oviduct. It was projecting from the isthmus into the shell gland. The egg had a shell which was thicker at the posterior end. Both the membrane and shell were incomplete at the anterior end. Several days before this bird died an egg similar to this one was found on the roosting boards of the pen in which she was kept. The funnel region of the oviduct was apparently normal. The glandular ridges were smeared over with what appeared to be albumen mixed with a small amount of yolk. At the anterior end of the albumen-secreting region the glandular ridges were very thick, and nodules of what appeared to be glandular tissue projected through the muscular layers. The region was somewhat contracted. Behind a narrow band of this tissue the duct was normal. In the body cavity free yolk was smeared over the intestines, and one yolk was walled off by peritoneum just below the ovary. Unfortunately no record was made of the contents of the egg found in the duct. Four of the eight dwarf eggs which were laid contained small drops or lumps of yolk. The other four were yolkless. All eight contained coagulation fibers which looked like normal chalazæ. The four yolkless ones contained no nucleus except these chalaza-like masses.

Apparently the ring of pathological tissue formed a partial constriction which hindered the passage of normal yolks. Yolks evidently entered the duct and were either extruded into the body cavity unbroken, or were broken and then entirely or mostly extruded. These yolks stimulated the secreting functions of the duct. In case all or most of the yolk was extruded the result was a dwarf egg. Three yolks evidently passed the obstruction unbroken and became the yolks of normal eggs.

Case 3 was that of a bird which was a fair producer during the early part of the season. She laid 150 eggs before July 1 and had always made some nesting records. The proportion of nesting records to eggs increased through the spring and early summer. In July there were as many nesting records as eggs. In August only two eggs were laid. The last of these, on August 27, was the last normal egg produced by this bird. From August 30 to October 16 the bird nested on every day except three. The only egg laid during this time was one dwarf, which was produced on September 16. The bird nested twice in November. There were two clutches of nesting records early in December. On December 13 the bird laid an egg which contained a normal yolk but which had a projection like a snail shell on the large end. The projection was formed of a membranous tube continuous with the egg membrane and filled with albumen. This tube was folded down onto the end of the other part of the egg and

was covered with a cap of shell. There was a distinct seam between the base of this cap and the shell which covered the rest of the egg, although they were continuous. Two days after this egg was laid the bird was killed, and an autopsy was performed. There was an egg in the oviduct just entering the isthmus. The lower end was covered with membrane. The upper end was prolonged into a string of albumen 5 or 6 mm. in diameter which extended 5 or 6 cm. up the duct. This egg then was similar to the egg laid two days previously in that it failed to round off normally at the anterior end. There was an abnormality of the oviduct which consisted in the presence of nodules of tissue in the glandular ridges of the funnel region. The nodules gave this lower portion of the funnel a quite abnormal appearance. Nodules were present in the peritoneum as well as in the oviduct. There were two large empty follicles on the ovary and a normal series of enlarging yolks, five of which were above 1 cm. in diameter. The other viscera were also normal. At the time of the autopsy the tumorous nodules in the lower funnel did not prevent the passage of yolks. The long series of nesting records at the time the dwarf egg was produced suggests that for a long period the pathological conditions of the duct may have prevented the passage of a normal yolk. The dwarf egg produced in the midst of this long series of nesting records contained some yolk wrapped in the chalazal fibers and some mixed with the thick albumen. The last normal egg had been laid 20 days before the dwarf egg. It seems therefore certain that the yolk in the dwarf egg was a part of a yolk which was broken either in the process of entering the duct or after it had entered. In the latter case the most of the yolk must have been extruded into the body cavity.

Another high producer which suffered a permanent disturbance which hindered normal-egg production was case 4. This bird produced 247 eggs during her first laying year. She had made occasional nesting records from the start, but the proportion of these to eggs increased markedly after July 1. There were, however, periods when the bird produced a litter of eggs without making nesting records. On February 13 of her record year the bird produced a dwarf egg. The egg which preceded this was a normal egg laid 13 days earlier. The dwarf egg contained chalaza-like coagulated albumen fibers, but no trace of yolk or other inclusion. Two days later the bird produced a normal egg. This was the last egg laid. Occasional nesting records followed. On May 5 (70 days after the last egg) the bird died and an autopsy was made. The ovary contained a normal series of enlarging yolks and four ruptured follicles. The body cavity contained a yellow fluid which was apparently a mixture of yolk and serum. A tumorous growth consisting of small solid tissue nodules was scattered all over the mesentery. A few nodules were present on the walls of the intestine. The upper half of the oviduct was badly diseased. The walls were thickened and hard. In places they were covered with large bunches of tumorous tissue.

This case again shows that a normal heavy-laying bird may develop a disease which affects the oviduct and prevents the passage of normal yolks, but which does not prevent the formation of yolks in the ovary. These yolks are ovulated into the body cavity. Since there was no yolk in the dwarf egg, it can not be proved that the egg formation was initiated by the entrance of a yolk which was later extruded. This may, however, have been the case. The occurrence of a normal egg only two days later shows that the ovary was in active condition. The immediate cessation of normal-egg production, the continued occasional occurrence of nesting records, and the condition of the ovary and oviduct at the autopsy strongly suggest that the passage through the duct was already considerably obstructed at the time the dwarf egg was produced.

The complete record of one more case (No. 5) is available. This bird did not begin to lay until November 13. She laid nearly continuously and made no nesting records until July 10. During this time (240 days) she produced 160 eggs. From July 10 to 23 the records show neither nesting nor eggs. This probably represents a normal period of nonproduction. No normal egg was produced by this bird after this period of nonproduction. On July 23 a dwarf egg was produced. This was followed by nesting records on the 24th and 27th. On the 31st another dwarf egg was produced. On August 3 and 4 the bird nested and on the 5th she produced a third dwarf egg. This was the last egg produced. From this time until the bird was killed (Sept. 2) nesting records continued to occur in series similar to the clutches of normal-egg production. We have no record or the contents of the dwarf egg produced on July 21. The eggs produced on July 23 and August 5 contained no yolk, but had as nuclei lumps of hardened albumen. The egg laid on August 5 was a dwarf egg which had a stalk attached to the large end. This stalk contained albumen and was covered with membrane and shell. To the lumps of albumen in this egg were attached long chalaza-like fibrous strings. One of these extended into the stalk. The autopsy record of this bird shows the ovary in a normal period of reproduction with a series of enlarging yolks, five of which were more than 1 cm. in diameter. There were four empty follicles visible. The anterior half of the oviduct was pathological. The walls were covered with a tumorous growth which appeared to be a proliferation of the muscular tissue. The outer layers of the walls of the intestine, portions of the oviduct ligament, and a small portion of the surface of the ovary contained small nodules of similar tissue. The body cavity contained a serous yellow liquid in which were lumps of yolk. The fact that the three dwarf eggs occurred between the production of the last normal egg and the complete cessation of egg production suggests that the disease may have gradually obstructed the passage through the duct. Whether or not the dwarf eggs were initiated by yolks which entered the duct and were later extruded can not be

decided, since they did not contain a trace of yolk. The continued occurrence of nesting records and the condition of the ovary at autopsy show that the reproductive cycles of the ovary were not interrupted. The dwarf eggs occurred during such a cycle.

The five cases of dwarf-egg producers cited above have several things in common: (1) Each bird was a normal, high-laying individual which became unable to produce normal eggs on account of a pathological condition of the oviduct. (2) In every case the part of the duct affected was the posterior end of the funnel, or the anterior end of the albumen-secreting region, or both. (3) The disturbance in each case was of a nature to constrict or prevent the normal expansion of the lumen of the duct. (4) In no case was the passage completely closed. (5) In each case there was convincing evidence that the ovary was in a normal reproductive cycle at the time the dwarf egg was produced.

Five of the sixteen[1] dwarf eggs produced by these birds contained as a nucleus a small quantity of yolk not inclosed in a vitelline membrane. This yolk was no doubt a part of a normal yolk, the rest of which was absorbed by the visceral peritoneum. Three of the five birds were absorbing yolk in this manner at the time of autopsy. The presence of a part of a yolk in the egg may have been due to any one of several causes. The three which seem most probable are the following:

1. A yolk may have been broken during its passage into the duct and only a part of it may have entered the duct.

2. A part of a yolk ovulated into the body cavity and, broken either before or after ovulation, may have been picked up by the funnel.

3. A normal yolk may have entered the duct and being unable to pass the pathological portion may have been broken and a part of it extruded into the body cavity. The remaining portion may have passed the obstruction, becoming the effective stimulus for the formation of the egg envelopes.

The effective stimulus in the case of the dwarf eggs which do not contain any yolk is difficult to ascertain. Some of these eggs contained what were apparently normal chalazæ. Most of them contained coagulated fibers which resembled the fibers of which chalazæ are formed. It is possible that in some or all of these cases a normal yolk has entered the duct, stimulated the upper duct to secrete chalazæ and some albumen, passed as far as the obstruction, and then been extruded, leaving behind sufficient chalazal material and albumen to furnish the mechanical stimulus necessary for the completion of the egg. Some of these eggs contained lumps of hardened albumen which may have arisen from albumen left in the duct or abnormally secreted. When the ovary is in a particular condition, such a mechanical stimulus may cause the secretion of the egg envelopes. It must be kept in mind, however, that a dwarf egg did not

[1] In two other cases the presence or absence of yolk was not recorded.

occur unless the ovary was actively producing yolks. In none of the above-mentioned cases was it impossible that a yolk had entered the duct and started the formation of the egg.

We have considered 5 of the 11 cases of dwarf-egg producers which were apparently permanently abnormal. Autopsies were not performed on the six other cases. The egg records for five of them (No. 6 to 10) resembled the egg records of the birds just discussed. No normal eggs were produced after the dwarf egg or eggs; also the birds made nesting records similar to egg records, indicating that the ovaries passed through normal reproductive cycles. The relation of the occurrence of dwarf eggs to normal eggs or nesting records was of a nature to show that they were produced only when the ovary was maturing yolks. Several of the dwarf eggs contained free yolk.

The record of the other bird (case 11) is worthy of special mention. This bird laid 17 dwarf eggs. These eggs were also produced when there was evidence that the ovary was in functional condition. The uniqueness of the case lies, first, in the unusual number of dwarf eggs, and second, in the fact that, although the number of dwarf eggs and nesting records and the proportion of these to normal eggs increased, some normal eggs were produced as long as there was any evidence that the bird's ovary was in laying condition. The egg record of this bird is given in Table XXIX.

TABLE XXIX.—*Egg record of case*[a]

Date.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Totals.
Sept.														n	n		1	1		n		n		1		1	1		1			6
Oct.	1		n		1	1		1		n		1		n			1		1		1		1	1		1		1		n		12
Nov.		n			1–			1		1			1		1		1		n													6
Dec.												1	n		1	1		1	1		1	1		1		1		1		1	1	12
Jan.		1		1	1			1		1		1		1		1		1	1		1		1		1							13
Feb.																							1			1	1		1			4
																																— 53
Mar.	1		1	1		1		1		n			1			1	1		1	1	1		1	1	1		1		1		1	17
Apr.	1		1	1		1	n	1		1		1		1		1	1		1–		1	1		1	1		1		1	1		18
May.		1		1		1		1		1–		1–			1		n		n		1–	n				n				n		8
																																— 96
June.	1–	1		n			1			1–	1		n	n		1	n	n	n	1–		1–	1			1–			1–	1		12
July.		1–	n		n	n	n		1		1	n	1					n		n			n				n				n	4
Aug.		1–			n	n		1–			1	n		1		1	1		1	n						1–1			1			[illegible]
																																— 122
Sept.	1	1–		n		n		n		n		n																				2
Oct.																																0
Nov.																																0
Dec.			1–				1							1																		3
Jan.																																0
Feb.																S																

[a] "1" denotes a normal egg, "1–" a dwarf egg, "n" a visit to a trap but no egg, and "s" date sold alive.

A record was made of the contents of 16 of these dwarf eggs. Not one of these contained yolk, but all of them contained varying amounts of chalaza-like fibers, some resembling normal chalazæ. Thirteen contained no visible nuclei except the mass of coagulation fibers. One egg (laid on August 26) also contained a small lump of hardened albumen. The one laid on June 26 contained, beside the mass of chalazal fibers, a

small lump of tough membrane resembling shell membrane. The one laid on June 10 contained what appeared to be an empty yolk membrane. It will be shown later that a dwarf egg sometimes contains a ruptured yolk membrane from which most of the yolk has escaped, but this membrane contained no yolk. If it was a yolk membrane, all of the yolk had been squeezed out.

It is of some interest that this bird was a breeder, and the normal eggs laid between February 23 and April 22 were incubated. All but two were fertile, and 44 per cent hatched. It will also be noted that on August 26 both a dwarf egg and a normal egg were produced.

The dwarf egg and nesting records of this bird seem to indicate some disturbance of the morphology or physiology of the oviduct, which frequently but not always interfered with the entrance of a normal yolk or prevented its passage through the duct. Since this bird was sold alive, there is no record of the condition of the sex organs. As in other cases of dwarf eggs without yolk, it is impossible to tell whether the eggs were initiated by a yolk which entered the duct and was then extruded, or whether the fibers of chalazal material or other inclusions were efficient stimuli.

B.—EVIDENCE FROM THE EGG RECORDS AND AUTOPSY RECORDS OF NORMAL DWARF-EGG PRODUCERS ON WHICH AUTOPSIES WERE PERFORMED

Attention has already been called to the fact that, while occasional cases occur where dwarf-egg production is due to a permanent disturbance of the reproductive apparatus, it is in general not associated with such a condition. In fact, a dwarf egg may occur at any time in a clutch or litter, the production of normal eggs continuing as if the dwarf had been a normal egg. In these cases the egg records give no hint as to the reason for the production of a dwarf egg. Our only data are obtained from the contents of the egg and the autopsy examination of the reproductive organs. Such autopsy records are available for 27 of the 189 dwarf-egg producers, which were apparently normal at the time of the production of the dwarf egg. In 4 cases a dwarf egg was found in the oviduct or body cavity at autopsy. Only one of these birds had previously laid a dwarf egg. In 3 cases the bird was killed a few hours after the dwarf egg was laid. Autopsies were made on 20 other cases from 9 to 508 days after a dwarf egg was laid. While the general or permanent morphological condition of the sex organs of a dwarf-egg producer is shown by each of these records, the temporary condition of the organs at the time a dwarf egg is produced is shown only by the cases on which autopsies were made while a dwarf egg was in the duct or within a few hours after such an egg was laid.

At the time of autopsy the sex organs of the birds which had produced a dwarf egg from 9 to 508 days before death were in every stage of repro-

ductive activity from strictly nonlaying to fully functional condition. Eighteen of the twenty showed reproductive organs which were in every respect normal for their functional condition. Each of these birds had produced a dwarf egg [1] in a regular series of normal eggs and had continued to produce normal eggs in regular cycles. These birds either made no nesting records, or a few such records were scattered among normal eggs, as is frequently the case with normal birds which have never produced dwarf eggs. Whether or not these occasional nesting records indicate ovulations into the body cavity has never been investigated. Observations made on a large series of autopsies on laying birds indicate that ovulation into the body cavity is not a very rare accident in birds with sex organs which are morphologically normal.

In each of the other two cases also the dwarf egg was produced in a regular series of normal eggs and normal-egg production continued in regular series for months (case 19, nine months, and case 20, five months) after the dwarf egg had been produced. Case 19 never made a nesting record until eight months after the dwarf egg had been laid. She then made two and laid a litter of 11 eggs. These were the last eggs produced. During the next three months she showed no evidence of reproductive activity (neither eggs nor nesting records). She began the last week of her life with a series of four nesting records on successive days. Three days after the last of these she died of peritonitis. At the autopsy the ovary contained a series of seven enlarged but absorbing yolks and two empty follicles which could be certainly identified. The body cavity contained free decomposing yolk. The upper part of the oviduct was filled with an egg concrement composed of successive layers of coagulated albumen formed around a small tumor which was attached by a narrow neck to a glandular ridge in the albumen-secreting portion of the duct. This tumor was about the size of a normal yolk.

Case 20 continued to lay normally for five months after the dwarf egg had been laid. Three nesting records were distributed separately among 100 normal eggs. The bird then appeared to pass through a normal nonproductive period of nine days. She then laid two eggs. A week later two clutches of nesting records occurred. During the next month she laid three eggs and made two nesting records. Occasional nesting records occurred during the next three months, but no more eggs were produced. The bird was then killed for data. At the autopsy the ovary contained a series of six enlarging yolks and three distinguishable follicles. The body cavity contained lumps of yolk. The funnel and the oviduct ligaments in the region of the funnel were pathological. They were red and fluted in appearance. The elongated lips of the funnel in the region of ligaments were fused together so that the opening of the funnel was no larger than the diameter of the tubular portion of the duct.

[1] In one case two and in another three at widely separated dates and each occurring in a series of normal eggs.

At the time of autopsy cases 19 and 20 showed a pathological condition of the oviduct which prevented the entrance of a normal yolk into the duct. The fact that these birds continued to be good layers for nine and five months, respectively, after the dwarf egg had been produced and then, by the cessation of normal-egg production and the occurrence of nesting records, showed a disturbance in their normal-egg production makes it seem probable that the pathological condition found at autopsy did not originate until some time after the dwarf egg had been produced. At least it is not safe to assert that a pathological condition of the duct existed at that time.

Of the seven cases of birds which either had a dwarf egg in the oviduct or body cavity at autopsy or had laid such an egg a few hours before death all had normal sex organs in fully functional condition. Each of these cases seems worthy of brief description. Case 21 was a late-hatched pullet which did not show any[1] reproductive activity until February. She then made a series of four nesting records and produced the dwarf egg as her first egg. The egg contained two small lumps of a dark, hard secretion and stringy albumen threads which looked like untwisted chalazæ. There was no yolk in this egg. The bird was killed a few hours after the egg was laid. She was in every way a normal healthy bird. The ovary contained a normal series of six enlarging yolks and four large and three small follicles. In the body cavity there were a few centimeters of a serous fluid containing yolk. In this fluid were found strings of tissue which may have been vitelline membrane. This pullet was then in full-laying condition; but for some reason not associated with an abnormality of the oviduct the yolks did not enter the duct, but were ovulated into the body cavity and absorbed. The origin of the stimulus which initiated the formation of the dwarf egg is not clear. While it is possible that all or part of a yolk entered the duct and was later extruded, there is no evidence for or against this view.

Case 22 was a normal pullet which had produced 48 normal eggs. She produced five normal eggs on successive days and on the sixth day produced the dwarf egg. The egg contained a lump or drop of yolk the size of a bean. The bird was killed a few hours after the egg was laid. The ovary contained a normal series of five enlarging yolks and four large and four small empty follicles. These follicles were all apparently normal and empty of yolk membranes. The body cavity contained a fluid which was partly yolk. In this case there can be no doubt that a normal yolk was ruptured either during ovulation or afterwards in the duct or body cavity and that a part entered or remained in the duct, forming the nucleus for the dwarf egg, while the rest was being absorbed by the visceral peritoneum.

[1] A lone nesting record occurred in December, but the bird may have accidentally gone into a nest.

Case 23 had been laying normally. The dwarf egg was the third egg in a clutch. This egg contained a peculiar nucleus. It appeared to be a yolk membrane constricted in the middle. One half of this membrane was filled with yolk and the other half with a clear liquid resembling thin albumen. The bird was killed a few hours after this egg had been produced. The sex organs were in normal active condition. There was no yolk in the body cavity. Evidently the abnormal yolk was extruded from a follicle which presented no abnormal appearance after the yolk was ovulated. Since this yolk was much smaller than a normal yolk, it is probable that it was formed in one of the smaller follicles.

Case 29 was killed by the other birds. She had laid a dwarf egg four months earlier and had continued to lay until six days before death. At autopsy a membrane-covered dwarf egg was found in the body cavity. It contained a small amount of very light-colored yolk. The albumen was greenish. The largest empty follicle on the ovary was not more than 5 mm. in diameter. There were a few shiny granules on the peritoneal surface which appeared to be remnants of absorbing yolk. Apparently the dwarf egg had remained in the oviduct or body cavity for several days, as the yolk it contained must have come from a follicle which was nearly absorbed. In this case also a part of a yolk seems to have been the stimulus which initiated the formation of the dwarf egg, while the rest of the yolk was absorbed from the body cavity.

Case 25 was a bird which had been presented by Dr. Edith M. Patch to the Maine Agricultural Experiment Station for dissection. This bird was kept at the Station plant for a few weeks. During this time she laid several normal eggs, but her trap-nest record was not kept. When she was killed for dissection, her sex organs were in a normal active condition. The ovary had a regular series of enlarging yolks and four empty follicles, two of which were nearly full size. The isthmus of the oviduct contained a normal membrane-shelled egg. A small dwarf egg was found in the shell gland. This egg contained coagulated fibers of albumen which resembled untwisted chalazæ. There was no yolk or nucleus other than the coagulation fibers. No yolk was found in the body cavity. If in this case the small egg had been initiated by a yolk which was returned to the body cavity and absorbed, the small egg must have been in the duct long enough for the absorption to have been completed. The size of the follicles on the ovary made this seem improbable. The origin of the chalaza-like bunch of coagulation fibers is not known. It seemed probable that these were the efficient initiating stimulus which started the secretion of the rest of the egg.

Case 26 died from some unknown cause. In the shell gland a dwarf egg was found. This egg contained as a nucleus a small lump of hardened secretion the size of a pinhead. The sex organs were in a normal

active condition except that the five yolks on the ovary were beginning to be absorbed. There were two large empty follicles. (The bird had not laid for five days before death.) The body cavity contained free yolk. This bird had also ovulated into the body cavity and was absorbing the yolks. Whether or not any of the yolk had entered the oviduct and initiated the secretion and then been expelled is not known. None of it remained in the egg.

Case 27 was found dead where she had hung herself in a feed rack. A dwarf egg was found in the shell gland. This egg is shown in Plate CXIII, figure 1. It contained two drops of yolk surrounded by albumen, egg membranes, and a thin layer of shell. The body cavity contained a yellow liquid which seemed to be a mixture of yolk and serum. The oviduct was in a normal active condition.

The ovary contained a series of enlarging yolks and ruptured follicles. From the largest one of the latter yolk was dripping. On examination it was found that the stigma or rupture line of this follicle was forked at the end. The follicle had ruptured only along the two short arms of this forked line. The yolk membrane was broken, but remained within the follicle. An examination of the follicles which contained the growing ova showed that three out of four of these had forked rupture lines. The follicles removed from this ovary are shown in Plate CXIII, figure 1. The last four (*c*, *d*, *e*, *f*) show the follicles containing complete ova. Follicles *c*, *d*, and *f* have forked stigmata, while *e* has a normal straight stigma. Follicle *b* is the one which contained the ruptured and nearly empty yolk membrane. It can be seen from the illustration that the straight part of the stigma is unbroken, while the forked part is open. In this case it seems clear that the incomplete rupture of the follicle resulted in the bursting of the yolk membrane. A part of the yolk entering the duct furnished the stimulus for the formation of the dwarf egg. The rest of the yolk was being absorbed by the visceral peritoneum.

C.—EVIDENCE IN CASES WHERE A DWARF EGG FORMS A PART OF A COMPOUND OR A DOUBLE EGG

a.—COMPOUND EGG OF WHICH ONE PART IS A DWARF EGG

Recently an abnormal egg was produced by a bird in the Station flock, which gives additional evidence as to the physiological conditions and nature of the stimuli which may result in the production of a dwarf egg. The shell of this egg is shown in Plate CXIII, figure 2. This egg was compound, and the two parts were of quite unequal size. The component which filled the larger part of the shell contained a normal yolk in a normal membrane but there was a slight tear in this membrane, and free yolk was protruding from this tear. The hole which faced the small component egg was quite small, and little of the yolk had escaped.

This part of the egg had normal chalazæ and thick and thin albumen. The other part, which filled the small portion of the shell, contained a drop of free yolk surrounded by a thick albumen envelope, which was quite distinct from the albumen of the large part of the egg. No thin albumen was present in this part of the egg. The egg had been opened by cutting and lifting off an elliptical piece of the large part of the shell. When the egg was turned out through this opening, only the large part came out. It was then seen that an incomplete shell membrane separated the two components.

This egg is analogous to the type of double-yolked eggs where the doubleness is visible externally by a depressed ring around the shell, and where internally there is a fold of shell membrane projecting into the deepest part of the furrow. In such double-yolked eggs the thick albumens are entirely separate. It has been pointed out by Curtis (5) that such an egg must come about from the union of two eggs while the first egg is entering the isthmus, since the formation of the egg membrane is a discrete process taking place immediately when the egg passes the isthmus ring.[1]

The compound egg described above evidently represents the union of a dwarf and a nearly normal egg at this point in the duct. The point of peculiar interest is that the yolk for the two parts of the egg seems to have come from the same normal yolk. The fact that the small component is situated at the end which would have been the pointed end of the larger part had it formed a single egg suggests that the dwarf egg preceded the normal egg through the duct. It is conceivable that during ovulation the yolk membrane was slightly ruptured and that a drop of free yolk entered the duct ahead of the main body of the yolk. While this seems the most probable explanation of the phenomenon, the shape of the egg may have been modified by the presence of a dwarf egg following. In this case the yolk may have been ruptured either before or after ovulation and a drop left behind may have stimulated the formation of the dwarf egg.

The bird which produced this compound egg succumbed to roup four days after this egg was laid. She laid a normal egg the day before she died and at autopsy a normal, soft-shelled egg was found in the shell gland. The reproductive organs were in normal active condition.

Two other compound eggs where one component was a dwarf egg have been produced at the station plant. In neither of these cases was there any external evidence of doubling. The eggs were about as broad as the average egg of the individual, but were perceptibly longer (in one case 13 mm.), so that they appeared very long and narrow compared to the other eggs of the birds. There was also no folding in of the egg membrane

[1] The fact that when an egg is entering the isthmus as much and only as much of it as has passed in is covered with membrane was first noted by Coste in 1874, and has since been observed by many investigators, including the authors (15, p. 106).

between the two parts, and thin albumen surrounded both thick albumen envelopes, which were distinct. In both cases the dwarf egg was at the pointed end and the normal egg at the blunt, or air-cell, end. In both cases the membrane of the yolk in the normal egg was uninjured. In neither case was there any yolk in the dwarf egg. The only visible nucleus in each case was a mass of chalaza-like coagulated albumen fibers. In these cases also the dwarf egg seems to have preceded the normal egg down the oviduct. The normal egg apparently overtook the dwarf egg at the end of the albumen-secreting portion of the duct. The origin of the coagulation fibers, which apparently furnish the stimulus for the formation of the dwarf egg in these cases, is not known.

In one case the compound egg was produced by a pullet one month after she began to lay. During this month the bird had produced nine eggs and nested without laying on eight days. The bird nested without laying on the first, third, fourth, and fifth days before the abnormal egg was produced. The day following the abnormal egg she neither nested nor laid. On the next two days she laid normal eggs. From this time on the number of nesting records decreased and the number of eggs increased. This is the only abnormal egg ever produced by this bird. She continued to lay well until sold at the end of her pullet year.

In the other case the bird was about a year old. At the time the egg was produced she had been laying steadily for a month and a half. All the eggs had been normal. The bird had not laid on the day preceding the production of the compound egg. On the following day she produced a dwarf egg which contained a mass of chalaza-like coagulated albumen fibers, but no yolk. These two abnormal eggs were the first eggs in a clutch of five, the three others of which were normal. The bird continued to lay for 4½ months—that is, until the end of August—never again producing an abnormal egg. She was sold one week after she stopped laying.

b.—DOUBLE EGGS IN WHICH THE INCLOSED EGG, AND SOMETIMES ALSO THE INCLOSING EGG, WAS DWARF

A dwarf egg is sometimes inclosed within a normal egg, or may furnish the nucleus of a larger dwarf egg (10). The cases of this kind which have occurred at the Station plant will in the near future be described in connection with a discussion of double or inclosed eggs. So far as possible, the description of cases will be left to a future paper. It seems necessary to summarize them here. A dwarf egg may be returned up the duct and meeting a normal egg may be included with it in a common set of egg envelopes. Of more interest to the present investigation are the cases where a dwarf egg is inclosed in a larger dwarf egg.

One case where such an egg was produced by a bird with a constricted ring of tissue in the upper oviduct has already been cited. This egg was the first of a series of three dwarf eggs. (See Table XXVIII.) The

nucleus in each of the other cases was hardened secretion. The inclosed egg was a very small-stalked dwarf egg with a hard shell. There was no yolk in either the inner or outer egg.

An egg similar to the one just described but much larger (weight, 32 gm.) was produced by a 2½-year-old bird which had laid normally until the end of her second breeding season. She stopped laying about the middle of June and showed no evidence of reproductive activity until the middle of August. She then began making nesting records. On the 25th she produced the double dwarf egg. A week later she was sold. The inclosed egg was a hard-shelled, stalked, dwarf egg which weighed 7 gm. The end of the stalk was open. This egg contained a mass of chalazal fibers and thin albumen. The long axis of the inclosed egg lay in the long axis of the inclosing egg. Coagulated albumen fibers like untwisted chalazæ were attached to both ends of the egg. The mass at the closed end of the inner egg contained a small cluster of yolk granules and a small lump of hardened secretion. The outer egg had both thick and thin albumen, normal egg membrane, and hard shell.

Four other cases have occurred at the Station plant where a very small dwarf egg has been the nucleus for a larger dwarf egg. In none of these cases was there any yolk in the outer egg, although in two of them there was a small amount of yolk in the inner egg. In each case the dwarf egg was covered by an egg membrane without shell. Each of the outer eggs had normal egg membranes and shell. In three cases there were bunches of coagulated albumen fibers resembling chalazæ attached to the poles of the inclosed dwarf egg. In each case the bird producing the egg was a normal heavy-laying bird and the egg occurred in a normal clutch of from two to five eggs. In each case the double egg was the only abnormal egg ever produced by the bird.

It thus seems that in normal birds in active laying condition a dwarf egg may be forced up the duct and may furnish the stimulus for the formation of a set of egg envelopes in which it becomes inclosed.

D.—EVIDENCE FROM EGG RECORDS AND EGG CONTENTS

It has been shown above that in cases of dwarf-egg producers on which autopsies were made, both normal and abnormal birds produced dwarf eggs only when the ovary was in active condition. All cases on which autopsies have been made with a dwarf egg in the oviduct, or within a few hours after a dwarf egg was laid, showed large empty follicles. Every case but one showed also that a yolk had been ovulated at almost precisely the time the secretion of the egg envelopes of the dwarf egg began. In the other case the ovary contained a series of absorbing follicles, two of which were very large, indicating that both had been discharged within two or three days at most. One of these had furnished

the yolk present in the normal egg found in the isthmus. Since the egg record of the bird is not available, it is impossible to say whether the yolk discharged from the second large follicle had been contained in a normal egg laid within a day or two before death, or whether it had been absorbed with great rapidity from the body cavity. It has been shown by Pearl and Curtis (6, 16) that "yolks and partly or fully formed eggs may be absorbed rapidly and in large numbers from the peritoneal surface." Previous observations, however, would not lead us to expect that within the normal period of the formation of an egg in the duct the absorption of a yolk would be so complete that no trace of it could be found. It seems probable that the sex organs remained in a condition capable of response to a stimulus for egg production for a few hours after ovulation. The presence of two large follicles, however, shows that in this case also the sex organs were in the extreme of active condition.

In case an autopsy was not performed upon a bird which produced a dwarf egg the morphological condition and the physiological state of the sex organs at the time the dwarf egg was laid can be judged reasonably accurately by the egg record. In all cases not discussed under the section on abnormal physiological conditions associated with dwarf-egg production the dwarf egg was produced within a litter all the other eggs of which were normal. As already shown, the dwarf egg took any position in the clutch and litter. In all cases there was abundant evidence from the egg record that the sex organs were in active condition and were capable of producing normal eggs.

In the center of the thick albumen of every dwarf egg examined was found some firmer material. In a number of cases this firmer nucleus was simply a few coagulated threads of albumen which resembled the threads of a normal chalaza. Sometimes the mass of threads has the appearance of a normal chalaza, but more often it is an irregular mass of untwisted threads. Such a mass of threads, or one, rarely two, more or less perfect chalaza, is present in nearly all the dwarf eggs. Frequently it is accompanied by one or more small slightly reddish lumps which appear to be hardened albumen, or by small blood clots, or more frequently still by a drop or more of yolk. It has already been stated that more than half of all the dwarf eggs collected contained some yolk not in a yolk membrane. In these cases the yolk is frequently surrounded by a membrane-like layer of coagulated albumen fibers resembling a chalazal membrane. In many cases nearly normal chalazæ are attached. The contents of such an egg is shown in Plate CXIII, figure 3. In most of these cases there is no normal yolk membrane in the egg, but in a few cases the dwarf egg contained a ruptured normal yolk membrane from which most of the yolk had escaped. Beside these, each of a number of dwarf eggs contained a small yolk without a germ disk but inclosed in a complete vitelline membrane.

Table XXX gives the number and percentage of each kind of dwarf eggs classified as to the nature of the contained nucleus.

TABLE XXX.—*Dwarf eggs classified according to the nature of the contained nucleus*

Nature of nucleus.	Number of dwarf eggs.	Percentage of dwarf eggs.	Subtotals of percentages.
Drop of yolk, no yolk membrane	141	51.46	
Broken yolk membrane with some yolk	10	3.65	55.11
Small complete yolk	27	9.85	64.96
Chalazal threads with or without lumps of coagulated albumen or blood clots	96	35.04	100.00
Total	274	100.00	

From Table XXX we see that 55.11 per cent of all the dwarf eggs opened contained a portion of a yolk, and 3.65 per cent contained a broken yolk membrane. This fact, in connection with the autopsy records already discussed for birds killed while a dwarf egg was in the duct or immediately after one was laid, indicates that in at least 55 per cent of the cases the immediate stimulus to the active duct was a part of an egg yolk, the rest of which was absorbed from the visceral peritoneum. In case 27, discussed on page 1027, the vitelline membrane of the yolk which furnished the stimulus was still within its ovarian follicle, although part of the yolk was in the dwarf egg in the shell gland and most of the rest in the body cavity. In this case the yolk was broken during ovulation, and only a part of it entered the duct. In the other case it is impossible to tell whether the yolk was broken during or after ovulation. It is possible either that the yolk was ovulated into the body cavity and subsequently broken and a part taken up by the duct; or on the other hand, it may have entered the duct and later been broken and a large part of it expelled.

Parker (10) described an ovum in ovo where the inclosed egg was yolkless and the inclosing egg contained a little "yolk substance." He believed that this "yolk substance" was the remnant of a normal yolk which had been ruptured and most of which had escaped. This suggested to him the question, "Is it possible that the yolkless condition of the inclosed egg is also due to the loss of its yolk?" However, he believes the evidence convincing "that albumen can be formed by the oviduct without the presence of yolk."

In 9.85 per cent of the dwarf eggs the stimulus to the active duct was an abnormally small yolk which for some unknown reason was produced and ovulated by the ovary. These cases apparently differ from normal egg production only quantitatively—that is, in the size of the stimulating yolk.

It is seen from Table XXX that 64.96 per cent of all the dwarf eggs produced were apparently initiated by the presence of yolk in the duct.

The presence of almost normal chalazæ in a few of the eggs without yolk suggests that a yolk may sometimes enter the duct, stimulate secretion of chalazæ, and then be extruded, leaving behind enough chalazæ and albumen to furnish the necessary stimulation for the completion of the egg.

X.—RELATION OF DWARF-EGG PRODUCTION TO OTHER OBSERVED PHENOMENA OF EGG PRODUCTION WHICH OCCUR IN NATURE OR HAVE BEEN EXPERIMENTALLY PRODUCED AND THE CONTRIBUTION OF THIS STUDY TO OUR KNOWLEDGE OF THE NORMAL PHYSIOLOGY OF EGG PRODUCTION

It has already been noted that five of the six birds on which autopsies had been performed while an egg was in the oviduct or immediately after one was laid were absorbing yolk through the visceral peritoneum. In three cases the dwarf egg also contained yolk. In two of the other cases, however, no yolk was found in the dwarf egg, although the body cavity contained yolk. This suggested, first, that ovulation or a specific condition of the sex organs immediately accompanying it was the essential stimulus for the secretion of the egg envelopes by the duct; or, second, that such a specific condition being present, the secretion of the egg envelopes was stimulated by the small lump of hardened albumen, which in these cases seemed to be the nucleus of the dwarf egg; or, third, that a yolk had entered and then been expelled from the duct.

That neither ovulation nor any condition of the sex organs associated with it is alone sufficient to cause the formation of a dwarf egg is certain. Birds known to have ovulated into the body cavity for a long time, due either to a morphological, physiological (6), or surgical (16) disturbance, which prevented the yolk from entering the duct but did not otherwise disturb the mechanism, did not produce dwarf eggs. Some stimulus other than the condition of the sex organs is necessary to start the secreting activity of the duct. In normal eggs and in dwarf eggs with yolk this stimulus (mechanical or chemical) is furnished by the yolk.

The fact that all dwarf eggs without yolks contain some nucleus firmer than normal albumen, together with the fact that in one case where the bird had a dwarf egg with such a nucleus in the shell gland at autopsy no yolk was found in the body cavity, suggests that when the sex organs are maturing and ovulating successive yolks from the ovary a mechanical stimulus may initiate the secretion of the egg envelopes.

Experiments performed by Tarchanoff (24) and Weidenfeld (27) have shown that a complete set of egg envelopes may be formed around an artificial yolk. Tarchanoff used an amber bead and Weidenfeld used an artificial yolk of wood or rubber. The authors, using a glass marble or an artificial yolk of agar, have confirmed this result. The experiments

have been referred to by one of the authors (5), but have not been described in detail. One of these eggs is shown in Plate CXIII, figure 4, *a*. The agar artificial yolk which formed the nucleus of this egg is shown in *b* of the same figure. This artificial yolk, which weighed 4.32 gm., was inserted through a slit in the middle of the albumen-secreting region and pushed posterior to the slit. The duct was tied on each side of the slit. The morning after the operation the membrane-shelled egg, which weighed 14.06 gm., was found on the floor of the cage.

In another successful case a glass marble coated with vaseline was inserted into the funnel, and the funnel was then closed by sewing the lips together. On the day following the operation the bird laid a hard-shelled egg which weighed 36.17 gm. This egg contained a small lump of vaseline as a nucleus. Six days after the operation the bird died. At autopsy the marble was found caught in the thread that sewed the mouth of the funnel. In this case it was impossible for a yolk to enter the duct, since the funnel lips were sewed together. The stimulation must have come from the marble or the vaseline.

Tarchanoff (24) notes that he obtained this result in only 1 out of 11 cases. The authors obtained a perfect result in only 2 out of 12 trials. Three other results were partially positive. In one case the bird was killed 24 hours after the operation and the agar yolk was found in the upper isthmus covered with a thin layer of thick albumen. In two other cases, where the birds succumbed to postoperative peritonitis, the artificial yolk, surrounded by a thin layer of coagulated albumen, was found in the duct at autopsy. In the other seven cases the artificial yolk was either laid without egg envelopes or was found naked in the duct at autopsy. All the birds used in these experiments were in active laying condition at the time of the operation. Two to three weeks after the operation autopsies were performed on five of the seven birds giving negative results. In two of these the sex organs were in the state to be expected in a bird which had stopped laying two or three weeks previously and was not approaching a new laying period. In the three other cases the sex organs were in functional condition, but no empty follicles were found on the ovary. We have noted elsewhere (16) that "a bird is usually not in laying condition for some time after any serious abdominal operation involving prolonged anesthesia and considerable surgical shock." Sellheim (23) notes that after removal of the oviduct the ovary at first shrinks; but since it comes again into functional condition, he believes that the postoperative shrinking is due to the severe operation. It seems that in the negative and partly positive cases described above the general physiological disturbance due to the operation may have lowered the general tone of the organism, or possibly the specific tone of the reproductive apparatus, to a point where the duct was unable to respond to stimulation in its normal manner.

The results show conclusively that in a certain stage of activity the oviduct responds to a mechanical stimulus by the secretion of the egg envelopes.

The fact that in a bird approaching a period of laying the oviduct enlarges as the yolk enlarges has long been recognized. In a bird which has not laid for two or three months and is not preparing for another production period the sex organs are in strictly nonfunctional condition. The ovarian eggs are scarcely larger than a pinpoint. The oviduct is a small, almost straight thin-walled tube, weighing from 2 to 3 per cent of its weight when in functional condition. As the ovary approaches laying condition, the oviduct enlarges. When the first group of oocytes start on their final growth period, the increase in the size of the duct is perceptible. By the time the first yolk is mature, the oviduct is also normally in functional condition. That this correlation is entirely due to the ovary is shown by the fact that the removal of the oviduct has no influence on the development or functional activity of the ovary (23, 16). Normally the oviduct is in functional condition only while the ovary is maturing yolks. The correlation is now commonly attributed to the internal secretion of the ovary. Bartelmez (1) working on pigeons states that "interstitial cells of the ovary show much greater signs of activity in functioning ovaries than do those in ovaries of birds that have not laid for a long time." A fact cited by Pearl and Curtis (16) indicates that the connection is not nervous, or at least that it is not conveyed to the oviduct through the nerves. This fact is that after the removal of a large part of the oviduct any part not removed passes through growth and cyclic changes associated with the periods of ovarian yolk production, exactly as though the duct were intact. Observations made in connection with other researches have shown that enlargement of the oviduct is not necessarily connected with yolk formation, although this is the normal relation. The two classes of exceptions that have been noted are: First, certain hermaphrodite fowls have been observed (14) that have ovaries largely made up of stroma rich in connective tissue and containing no large follicles, and yet these birds had oviducts from one-half to three-fourths the size of a functional duct; and, second, birds with certain types of ovarian tumors, but without enlarging yolks, have been observed to have nearly functional-sized ducts.

These facts taken together indicate that the functional condition of the oviduct depends upon some substance formed in the ovary, usually at the time yolks are maturing, but in certain pathological cases at other times also. This substance is probably an internal secretion carried by the blood, since the ovary can cause the enlargement to functional size of a small piece of oviduct the normal nervous connections of which have been destroyed. The fact that dwarf eggs are produced only when the bird is maturing and ovulating yolks and the fact that more than 50

per cent of the trials to induce egg formation around artificial yolks were failures suggest that the sex organs must be and must remain in absolute functional condition until the egg is completed.

Loeb (9) showed that the mammalian uterus responds to a mechanical stimulus by the formation of the maternal placenta during a definite period after ovulation. He finds that during this period the uterus is sensitized by the internal secretion of the corpus luteum. We may conceive that the specific state of the oviduct in the fowl which renders it capable of responding to mechanical stimulation, be it yolk or foreign body, is associated with some quantitative or qualitative difference in the internal secretion of the ovary. While from the data given above it is possible that it is due to some postovulation change in the ovary, this seems improbable. We know that in many and probably in most cases in normal-egg production the duct responds to the first yolk of a series ovulated. This response occurs immediately after ovulation—that is, there is not sufficient time for a change in the internal secretion of the ovary occurring at or after ovulation to affect the state of the duct.

An observation made some time ago also has a bearing on this point. A bird which had laid three days earlier was selected for an abdominal operation. She was accidentally killed with an overdose of ether just after the incision was made. The oviduct did not contain an egg, but the funnel was in active motion when first observed. It responded quickly and sharply when stimulated by pinching with the forceps. The albumen region also responded to this stimulus by strong peristaltic movements. A 10-cm. piece from the albumen-secreting region of this very active duct was cut open lengthwise and spread out flat with the glandular surface exposed in a warm damp chamber moistened with salt solution. Small bits of cork were scattered on the surface in order to study ciliary motion. The ciliary activity continued for 1½ hours. At the end of this time it was noted that a very thin film of albumen was visible on the surface of the mucosa. In this case an isolated piece of oviduct responded to mechanical stimulation by the secretion of a very small amount of albumen. This duct had not been sensitized by an immediately preceding ovulation. The last ovulation had taken place four days before the bird was killed. The active movements of the funnel when the body cavity was opened suggested that an ovulation was about to take place. Either the duct had remained in a condition capable of a secretory response for four days or it had again come into such a condition with the maturing of another yolk.

The above-described experimental work and the observations on the conditions under which dwarf eggs are produced indicates that mechanical stimulation of the oviduct results in the formation of egg envelopes only under a particular condition of the duct which seems to be associated with the maturing of yolks by the ovary. The sensitization of duct, if this is the proper explanation of the phenomena observed,

apparently precedes ovulation. Further work is necessary, however, to determine the factors involved in the specific condition of the duct which causes it to respond to stimulation by the secretion of the egg envelopes.

It would seem from the above considerations that the presence in a completely functional oviduct of a small solid or semisolid substance capable of presenting a mechanical stimulation may cause the production of a dwarf egg. Nearly two-thirds of the dwarf eggs, however, are known to be initiated either by abnormally small yolks or by parts of broken yolks. Their production may be associated with an abnormal condition of the ovary or with pathological conditions of the duct, but even in these cases the result was due not to the abnormality per se but to the fact that this abnormality prevented the entrance of a normal yolk or obstructed its passage through the duct.

The mechanical stimulus need not begin at the funnel in order to be effective to the parts of the duct lower down. In Tarchanoff's case (24) and in one of our own cases of perfect egg formation around an artificial yolk, the yolk was inserted into the duct through a slit in the albumen portion, the duct being tied off above this point. Pearl and Surface (18) showed that a mechanical stimulation (in this case feces introduced by anastomosing the intestine to the side of the uterus) caused the formation of shell by the uterus.

The mechanical stimulation is of local character—that is, it is not transmitted down the duct for any measurable distance below the point where it is applied. Pearl and Curtis (16) have shown that "the stimulation of the advancing egg is necessary for the discharge of the secretion of the duct, since a duct closed at any level functions only to the point where the passage is interrupted." In the cases of dwarf-egg producers with pathological ducts the abnormality of the duct was in each case of a nature to constrict but not close the lumen of the duct. Several eggs produced by these birds contained lumps of yolk, indicating that the nucleus of the egg had passed the constricted portion.

SUMMARY

(1) During the eight years from February 1, 1908, to February 1, 1916, 298 dwarf eggs are known to have been produced at the poultry plant of the Maine Experiment Station.

(2) During the two years of maximum dwarf-egg production the ratio of dwarf eggs to normal eggs was 1 dwarf egg to 1,158 normal eggs.

(3) Dwarf eggs are of two distinct types in respect to shape: First, the prolate-spheroidal type, and second, the cylindrical type.

(4) Dwarf eggs of the prolate-spheroidal type are much more frequently produced than the cylindrical type. In fact 95.4 per cent of the dwarf eggs studied were prolate spheroids.

(5) Dwarf eggs may also be classified according to the absence of yolk or its presence either as a small yolk in a yolk membrane or as free yolk.

(6) Of the 274 dwarf eggs opened 35.03 per cent were yolkless and 64.96 per cent, or nearly two-thirds, contained yolk. The yolk was inclosed in membrane in only 9.85 per cent of the dwarf eggs opened, while free yolk was present in 55.11 per cent of these eggs.

(7) Dwarf eggs with small yolks, while distinctly smaller than normal eggs, are significantly larger than dwarf eggs with little or no yolk.

(8) A comparison of the relative size of the several groups of dwarf eggs, normal eggs, double-yolked and triple-yolked eggs furnish a continuous line of evidence that the amount of albumen secreted depends to a large extent at least upon the degree of immediate stimulation due to the amount of yolk present.

(9) Although the evidence available is not sufficient for a positive statement, the shape of the cylindrical egg is probably due to the long form of the stimulating nucleus.

(10) Dwarf eggs with small yolks have indices which are higher than those for normal eggs and lower than those for other prolate-spheroidal dwarf eggs. This difference in index in the three groups is the reverse of their difference in size.

(11) This negative correlation between the shape, index, and size extends the evidence from former researches that the smaller the egg the broader it is in proportion to its length.

(12) Two factors may be involved in producing this negative correlation between shape index and size: First, the area of the glandular mucosa under stimulation at any one time must be related to the size, particularly the length, of the stimulating nucleus (yolk drop, normal yolk, or two or three yolks in tandem). Second, the oviduct, which is a tube with elastic walls, will offer more resistance to the passage of a large than a small body, and therefore when the plastic egg is forced through it by peristalsis it will exert a greater elongating pressure upon a large than a small egg.

(13) Dwarf eggs of each class are exceedingly variable when compared to normal eggs. This greater variation occurs in all the physical characters measured—that is, length, breadth, shape index, egg weight, yolk weight, shell weight, and possibly albumen weight.

(14) Dwarf eggs with small yolk resemble normal eggs in degree of variability as well as in size and shape more nearly than do other classes of dwarf eggs.

(15) The several size characters show different degrees of variation. They may be arranged from most to least variable as follows: Egg weight, length, and breadth. This arrangement is the same for dwarf and normal eggs.

(16) It is probable that the variation in yolk weight compared to the variation in the other egg parts and to the whole egg is greater in dwarf eggs with small yolks than in normal eggs.

(17) The interrelation of the size and shape characters in prolate-spheroidal [1] dwarf eggs of each class is as follows:

a. Length and breadth, length and weight, and breadth and weight are significantly highly correlated in eggs of each group.

b. Index and weight are negatively correlated. The correlation is significant for dwarf eggs with little or no yolk.

c. In dwarf eggs with small yolks, yolk weight is highly correlated both with egg weight and with albumen weight.

The physiological significance of these correlations is discussed.

(18) During the last eight years 5.15 per cent of all the birds kept at the Maine Station plant are known to have produced at least one dwarf egg.

(19) Both the actual dwarf-egg production and the number of dwarf eggs per 1,000 eggs is lowest during the winter months. It increases through the spring, reaching a maximum in the early summer.

(20) In general the season of high normal-egg production is also the season for high dwarf-egg production both actual and relative to normal-egg production. The maximum of dwarf-egg production, however, occurs later in the season than the maximum normal-egg production.

(21) The production of a dwarf egg is usually an isolated phenomenon occurring only once or twice during the life of a bird. Only 3.5 per cent of the birds which produced one or more dwarf eggs produced more than two.

(22) A study of all the egg records and the available autopsy records for birds which produced one or more dwarf eggs shows that in most cases the disturbance which caused the production of the dwarf egg was of temporary character and was not correlated with a morphological disturbance of the sex organs.

(23) Eleven of the two hundred dwarf-egg producers, however, showed evidence that a permanent disturbance had occurred. In these cases few or no normal eggs were produced after the dwarf egg or eggs, although nesting records indicate that the ovary passed through normal reproductive cycles.

(24) Autopsies were made on five of these cases, and all of them showed some pathological condition of the oviduct which interfered with the passage of the egg, but did not entirely close the duct.

(25) In normal birds dwarf-egg production is most likely to occur during the height of the breeding season. It is not associated with immaturity of the sex organs.

[1] The same relations apparently also hold for cylindrical dwarf eggs, but the number observed was too small to determine the degree of relationship.

(26) The popular notion that a dwarf egg marks the end of a period of production is without foundation. A dwarf egg is equally likely to occur at any time during a clutch or litter.

(27) A dwarf egg may be overtaken by a normal egg and form one of the components of a compound egg similar to a double-yolked egg except that one part is a dwarf egg.

(28) A dwarf egg after it has received its membrane or its membrane and shell may be returned up the duct and be included in the succeeding normal egg, or it may act as the stimulus for the formation of a larger inclosing dwarf egg.

(29) Dwarf eggs are produced only when the ovary is in the absolutely active condition associated with the maturing of yolks. This is true whether the bird has a normal or pathological oviduct.

(30) When the sex organs are in this condition, a mechanical stimulation of the oviduct by an artificial yolk may result in the formation of a complete set of egg envelopes.

(31) The mechanical stimulation need not begin at the funnel in order to be effective to the parts lower down.

(32) The mechanical stimulation is local in its effect—that is, it is not transmitted down the duct any distance below the point to which it is applied.

(33) Dwarf eggs may be and probably often are produced by the stimulation of an active duct by some material particle which is not yolk.

(34) At least 65 per cent of the dwarf eggs studied, however, were initiated by an abnormal small yolk or by a part of a normal yolk. Certainly in some and probably in all the latter cases the rest of the yolk was absorbed by the visceral peritoneum.

(35) Neither the absolute time relation between ovulation and the ability of the duct to respond to mechanical stimulation nor the nature of the connection between the state of the ovary and the duct is certainly known.

(36) It is suggested that the oviduct may be sensitized by some change in the internal secretion of the ovary associated with the maturation of yolks.

(37) It is also pointed out that if this is the case the change in the secretion probably precedes ovulation.

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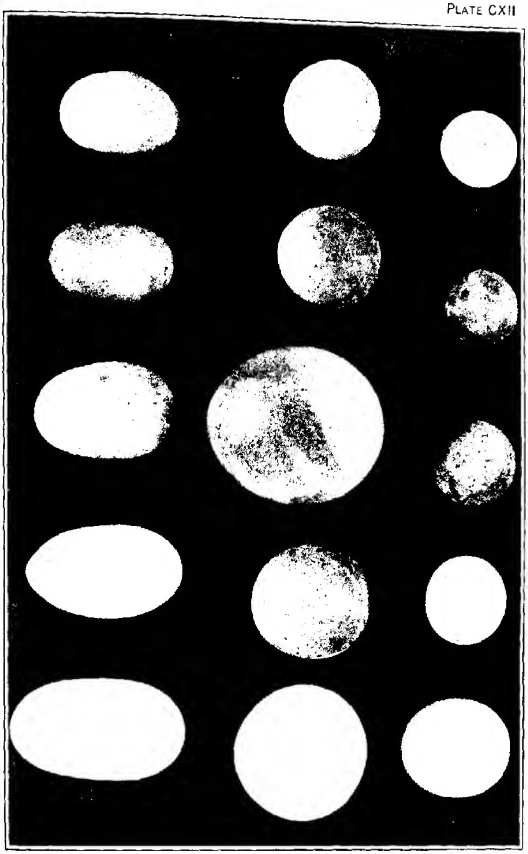
PLATE CXII

A collection of dwarf eggs with a normal egg in the center of the group. $\times 2/3$.



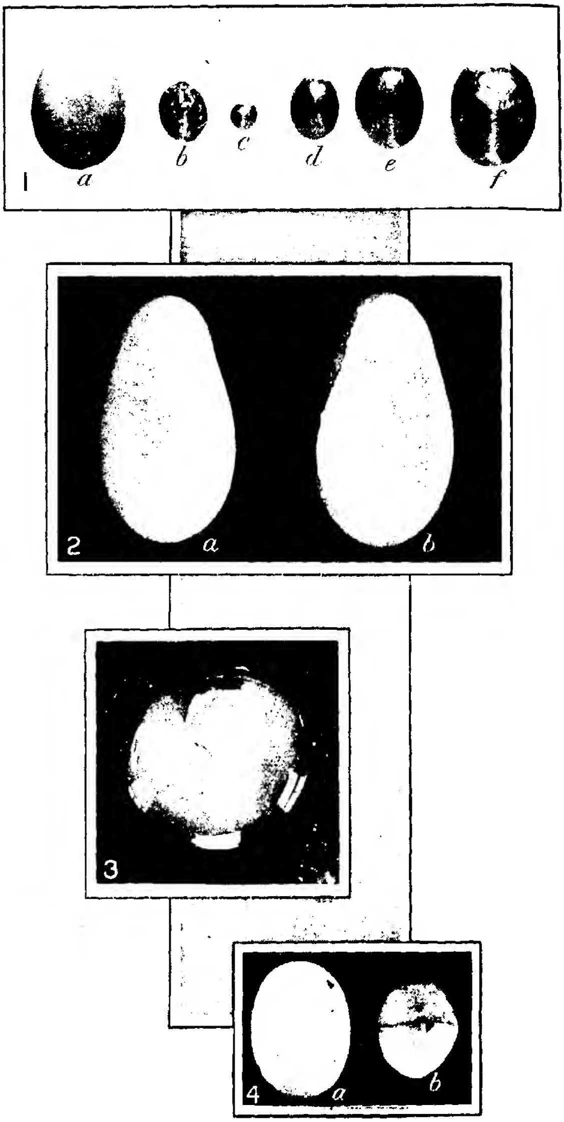

1 a b c d e f
2 a b
3
4 a b

PLATE CXIII

Fig. 1.—Ovarian follicles (*b*-*f*) and the dwarf egg *a* from case 27. Follicle *e* has a normal straight stigma. Follicles *b*, *c*, *d*, and *f* have stigmata which are forked at the end. The forked portion of the stigma of *b* has ruptured; the yolk membrane is broken and most of the yolk has escaped. Part of the escaped yolk was in the body cavity and part formed the nucleus of the dwarf egg *a*. $\times$ 2/3.

Fig. 2.—Shell of a compound egg which was composed of two albumen masses partly separated at the level of the seam in the shell by an incomplete egg membrane. The larger component contained a normal yolk with a slight puncture in the yolk membrane. The smaller one contained a drop of yolk which apparently came from the yolk in the other part. *a*, Outside view of shell; *b*, inside view. $\times$ 2/3.

Fig. 3.—Dwarf egg containing a mass of yolk not in a yolk membrane, but separated from the albumen by a membrane-like layer of chalazal threads. Note nearly normal chalazæ. $\times$ 2/3.

Fig. 4.—Dwarf egg formed around an artificial yolk of agar which was inserted into the oviduct. *a*, Complete egg; *b*, agar yolk. $\times$ 2/3.

α-CROTONIC ACID, A SOIL CONSTITUENT

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In a preliminary examination of a sample of Susquehanna fine sandy loam soil from Texas, which was made in October, 1915, by Dr. E. C. Shorey, who was at that time connected with the Office of Soil-Fertility Investigations, an unsaturated organic acid was isolated. In a subsequent examination of the same soil by the writers this compound was again isolated, and its identity with α-crotonic acid has now been established.

The soil was taken from an infertile spot in a field near Marshall, Tex. The infertile spots, which are devoid of all vegetation, have been observed for three years in this locality, and the area of these spots is gradually increasing.

The soil in this district is described as a Susquehanna fine sandy loam, from 8 to 18 inches deep, with an average of about 14 inches (8).[1] The subsoil is a stiff clay of a red color or red mottled with yellow and gray extending to a depth of several feet. The color of the soil is prevailingly gray, but for a few inches above the subsoil it has a reddish cast. Because of the impervious nature of the subsoil, the drainage is very poor, and special methods of soil management, with the object of producing better drainage, have been recommended and to a limited extent practiced. This soil is deficient in lime or other basic material and is very poorly drained. It has also been found to have a high reducing power and a rather low oxidizing power. It therefore seems to present optimum conditions for the formation and accumulation of organic acids.

In the isolation of α-crotonic acid an alkaline extract was obtained by treating the soil with an aqueous 2 per cent sodium-hydroxid solution for 24 hours at room temperature. The extract was made slightly acid with sulphuric acid and filtered. The acid filtrate was then extracted with ether and the ether extract was evaporated to about 200 c. c. and shaken up with a concentrated solution of sodium bisulphite to remove aldehydes or other substances which combine with this reagent.

The bisulphite solution was drawn off and extracted several times with fresh ether. All of the ether extracts were then combined and slowly evaporated to a brown sirup in a small crystallizing dish. At this point the dish was covered with a watch glass containing ether and maintained at a low temperature on a steam bath. A white crystalline solid gradually sublimed on the watch glass. The sublimed substance was dried between filter paper and recrystallized from petroleum ether.

[1] Reference is made by number to "Literature cited," p. 1045.

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The substance was further purified by subliming several times at a low temperature and was dried over anhydrous calcium chlorid.

The properties of the substance thus obtained were found to be identical with those of α-crotonic acid. The purified soil substance melts at 72° C., while α-crotonic acid melts at 72°. A mixture of Kahlbaum's chemically pure α-crotonic acid (further purified by sublimation) and the soil compound melted at 72°.[1]

The purified soil compound is soluble in water, ether, alcohol, and slightly soluble in cold and more soluble in hot petroleum ether. It has a sharp odor somewhat similar to that of butyric acid, although much milder. It readily reduces potassium permanganate in a cold alkaline solution. In a cold aqueous solution it decolorizes bromin instantaneously, but does not decolorize bromin in carbon tetrachlorid. With ferric chlorid it gives an orange color on the spot plate. In aqueous solution it does not reduce gold chlorid in the cold.

A determination of the neutralization equivalent (molecular weight) gave the following results: 45.3 mgm. of the soil compound required 10.43 c. c. of *N/10* sodium hydroxid (NaOH) for complete neutralization with phenolphthalein as the indicator.

The neutralization equivalent was found to be equal to 86.8.

The neutralization equivalent calculated for crotonic acid (CH_3CH:-CH.COOH) is 86.05.

The soil substance sublimes readily at room temperature, which is in accord with the observation made by Bulk (1).

These reactions and tests on the soil compound and synthetic α-crotonic acid were carried out simultaneously and were found to be identical in every case. The crystalline forms were also found to be the same. Figures 1 and 2 of Plate CXIV show the form and similarity of the crystals obtained in the first stage of sublimation. During the process of sublimation the crystals grow into large irregular plates or leaflets.

Ninety-four mgm. of the acid were obtained from 50 pounds of soil. This quantity would correspond approximately to 16 pounds per acre. It is obvious from the very unusual properties of this substance that a considerable amount would be lost in the processes of isolation and purification, and the actual amount present in the soil would be much greater than 16 pounds per acre, which is therefore a minimal value.

The α- and β-crotonic acids are unsaturated and have the formula CH_3CH:CH.COOH. These acids are typical examples of compounds which exhibit geometrical isomerism. Their structures have been dwelt

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[1] In all cases a slight softening or sintering at 69° to 70° was observed, which may be due to the presence of traces of β-crotonic acid. Morrell and Hanson (4, p. 1522) have shown that α-crotonic acid, when heated above its melting point, is partially converted into β-crotonic acid in amounts varying with the temperature. This study indicated the advisability of subliming α-crotonic acid at a low temperature in purifying it in our work. In order to prevent the loss of material by sublimation, the melting points were made in sealed tubes which were completely submerged.

upon by numerous investigators (7) and are represented by the following formulæ:

$$\begin{array}{c} CH_3.CH \\ \| \\ HC.COOH \end{array} \qquad\qquad \begin{array}{c} CH_3.CH \\ \| \\ HOOC.CH \end{array}$$

α-crotonic acid β-crotonic acid

Heretofore the occurrence in nature of crotonic acid has not been firmly established, and the formation in soils of a compound possessing such unusual chemical properties and structure is very difficult to explain. Schlippe (6) described an acid from croton oil which had the formula $C_4H_6O_2$ and to which he gave the name "crotonic acid," but later investigations (2) on this oil have failed to show the presence of crotonic acid. β-Hydroxybutyric acid, which is present in diabetic urine, is readily converted into α-crotonic acid by heating either alone or with dilute sulphuric acid (5).

α-Crotonic acid is also produced from allyl cyanid, which is a constituent of mustard oil. Krämer and Grodzki (3) have isolated crotonic and isocrotonic acids from pyroligneous acid obtained by the dry distillation of wood.

These methods of obtaining α-crotonic acid suggest the possibility of its formation in soils during the destruction of cellulose, from β-hydroxy acids of the aliphatic series, or by the hydrolysis of allyl cyanid, which is found in the essential oils from certain plants.

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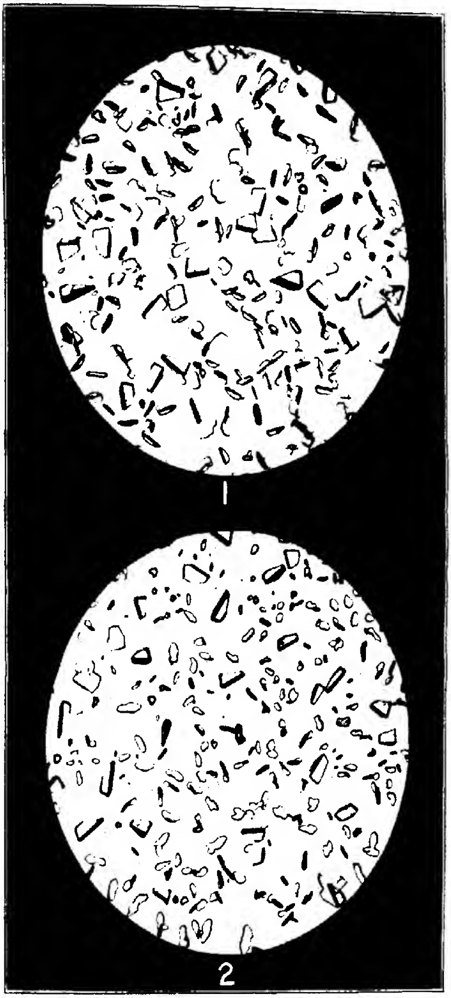
PLATE CXIV

Fig. 1.—α-Crotonic acid from soil. × 210.
Fig. 2.—Synthetic α-crotonic acid. × 210.


1
2

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